FLEET

ARC CENTRE OF EXCELLENCE IN
FUTURE LOW-ENERGY
ELECTRONICS TECHNOLOGIES

ANNUAL REPORT 2023

FLEET operates on the lands of

the Wurundjeri and Bunurong people of the Kulin nations (Narrm, Melbourne),
the Bedigal and Gadigal people of the Eora Nation (Gadigal Country, Sydney),
the Dharawal people (Wollongong),
the Ngunnawal and Ngambri people (Canberra),
and the Turrbal and Yugara people (Meanjin, Brisbane).

→ **FLEET PATHWAY TO IMPACT**

→ **RESEARCH TRANSLATION**

→ **2023 HIGHLIGHTS**

→ **FLEET TEAM**

FLEET draws upon leading national and international experts to fulfil the Centre's mission.

INTRODUCTION

KEY DATA

14
INTERNATIONAL PARTNER ORGANISATIONS

188
INVESTIGATORS AND RESEARCH ASSOCIATES

217
CENTRE MEMBERS AND AFFILIATES

20
RESEARCH LEADERS FROM 7 AUSTRALIAN UNIVERSITIES

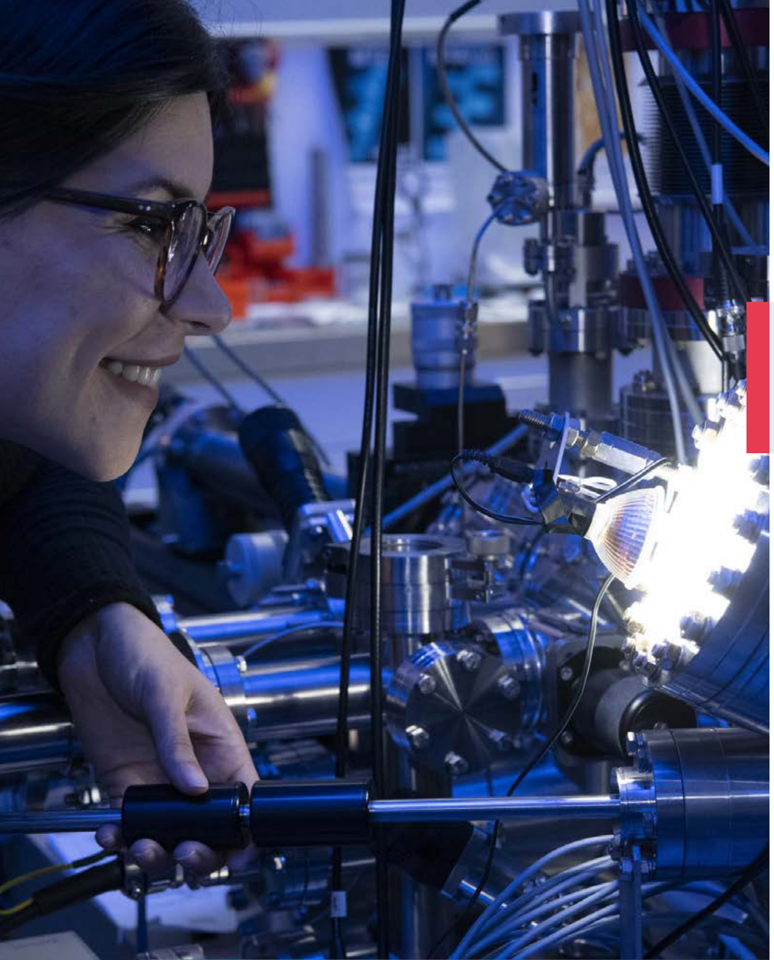
33
EARLY CAREER RESEARCHERS

RESEARCH FUNDING

$45.2M
2017-2023

$6.8M
in 2023

FLEET LAUNCHED
12 June 2018



Vision

FLEET has laid the foundations for a lasting legacy in 2023.

While progress on FLEET's core research mission continues (see highlights in Director's message p11), FLEET has directed strategic efforts in 2023 towards ensuring that the research capacity FLEET has built, the far-reaching network it has brought together, and the alums it has educated and trained will continue to make a positive impact on society well beyond FLEET's period of performance.

ENSURING FLEET'S LEGACY

The year 2023 marked FLEET's last full year of operations, as FLEET will cease operations funded by the Australian Research Council (ARC) in mid-2024.

While FLEET's core research mission continues at full steam during this final period, FLEET's strategic activities have been increasingly directed towards ensuring a lasting legacy beyond the life of the Centre. This effort is multi-faceted. FLEET is planning for major research activities and collaborations beyond the Centre's operation period. The Centre is ensuring that FLEET research is translated beyond the laboratory to maximise its impact. We are providing the best launching pad for FLEET researchers to succeed in their next endeavours. And we are quantifying and taking stock of FLEET's successes, and failures, in order to better inform future Centres of Excellence.

In March 2023 FLEET ran the Future of Electronic Materials Research in Australia (FEMRA) Workshop. The over 80 attendees largely represented Australian investigators in the broad areas of electronic and optical applications of materials but also included several international partners, reflecting the strong leadership role FLEET has played in this field. The FEMRA Workshop was designed to be self-organised, divided into separate symposia, with proposals for symposia organisation accepted from any interested parties. In the end, four symposia were held in the areas of topological materials, materials for quantum simulation, materials for quantum information technologies, and strong light-matter interactions in materials. Each made a compelling case for Australia's unique research strength and capacity in these areas. Two of these areas have already nucleated bids for 2026 Centres of Excellence, now in the planning stages, and others are expected to be growth areas in Australia in the future.

More at FLEET.org.au/alumni

Right: Dr Tich-Lam Nguyen showcased FLEET's areas of impact in her keynote presentation at the ATSE Visionary Leadership event 'Connecting Pathways'

ACHIEVEMENTS

FLEET has continued to exceed its targets in number of research outputs. However, this does not tell the full story: two aspects of FLEET's research outputs stand out.

First, FLEET set a KPI for quality of research outputs, aiming for 20% of outputs to be published in outlets with impact factor (IF) greater than 7. FLEET has consistently managed to publish more than 50% of research outputs in high-impact (IF > 7) outlets. This emphasises that FLEET has produced a high quantity of research outputs, the quality of which has greatly exceeded our ambitious expectations. This reflects both the quality of the research and the recognition by editors and reviewers that the work of the Centre is impactful.

Second, FLEET's publications reflect the growth of a strong and productive collaborative network. The vast majority of FLEET's publications (72%) are collaborative in nature, involving more than one chief investigator, a partner or associate investigator, and/or more than one node. Furthermore, collaborative papers have had higher impact than single-investigator papers, demonstrating the benefit of a coordinated Centre approach in accomplishing impactful research.

FLEET continues to hit its twice-expanded targets for mentions of FLEET research in the media. FLEET's powerhouse communications effort is the result of a strategy of enabling its members to be self-sufficient in doing their own communications.

This is reflected in FLEET members in 2023 writing 15 non-peer-reviewed articles, which were published on FLEET's website. Of those member-authored articles, seven science-based articles were republished a total of 71 times on scientific platforms. This 'teach a scientist to fish' approach to communications will have a legacy of career-long benefits to the hundreds of young researchers who have worked with FLEET.

FLEET has specifically aimed to grow the next generation of women science leaders. In 2023 FLEET examined through a survey the experiences of 18 women in FLEET who have gone through Women in Leadership training programs (see p21). The survey results highlight a range of specific skills and strategies that made an impact as these women moved to new positions as tenure-track academics or in high-level scientific management roles as Centre and Department Managers.

FLEET delivered 11 training and development workshops to its members in 2023 and also funded opportunities for members to seek their own training in career planning, commercialisation, leadership and other areas.

FLEET's mentorship network was expanded in 2023 as FLEET co-founded a new combined mentoring network connecting mentors and mentees across 12 Centres of Excellence. The network has the capacity to be self-sustaining, adding new Centres as they come online.

FLEET has adopted an innovative outreach model that aims to involve all members (from the Director to students) in outreach activities each year. This has enabled FLEET to reach an extraordinary number of people with outreach activities: more than 28,000 primary and secondary students, and 44,000 members of the public over the life of the Centre.

As FLEET has pursued this model, an additional benefit has become clear: FLEET members see their experience in delivering outreach programs as valuable training in communicating to the public about science, which will serve them throughout their careers.

Over the years 2017 to 2023, 179 FLEET members have participated in outreach activities; an impressive participation rate of 74%.

FLEET has also recognised the power of putting women forward as the face of science. The year 2023 featured almost 40 appearances of women in public-facing events, with women featuring at nearly 80% of all public FLEET outreach events. Women in FLEET also developed and delivered lessons for the Future Electronics unit at the John Monash Science School, giving an opportunity for high school students to see successful women in science first-hand.

Evaluating the impact of FLEET's outreach has become a key focus as FLEET reviews its legacy. Surveys conducted of attendees before and after FLEET's exhibition at the Sydney Science Trail Expo showed that most entered with little awareness of the energy consumed by digital electronics but came away with increased awareness and new perspectives on how society uses digital technologies. FLEET also embedded pre- and post-workshop evaluation into nine 'quantum circuit' workshops for primary school students, finding that the workshops had an impact on students' understanding of several key quantum concepts.

TAKING STOCK OF FLEET'S LEGACY

FLEET embarked on a comprehensive evaluation of the Centre's accomplishments, spearheaded by the business team.

The Centre's activities thus far were meticulously assessed, focusing on key achievements relative to the objectives of the Centre of Excellence grant scheme. The findings were mapped against the most impactful areas, aligned with the United Nation's Sustainable Development Goals.

A review of these outcomes by FLEET's Executive Committee marked the transition to the subsequent phase: pinpointing key case studies that underscore the Centre's impact.

Through this evaluative process, six areas of impact were identified: knowledge generation, capacity building, sustainability, STEM education, innovation 'outside the lab', and leadership.

These align with the UN's Sustainable Development Goals 4 (quality education), 7 (affordable and clean energy), 8 (decent work and economic growth), and 9 (industry innovation and infrastructure).

This year, in addition to FLEET's Annual Meeting held in Lorne, Victoria, in July 2023, FLEET organised a second all-hands meeting focused on FLEET's legacy. This was held from 29 November to 1 December on the Gold Coast, Queensland.

The Legacy Workshop reflected on FLEET's history since the very first meeting of FLEET, also held on the Gold Coast, in February 2017, with just 25 key researchers and Dr Tich-Lam Nguyen, FLEET's Chief Operating Officer (COO).

It was at this 2017 meeting that FLEET's governance structure and strategic plan were laid down to deliver the Centre's agreed key objectives.

At the 2023 Legacy Meeting, Tich-Lam unveiled FLEET's comprehensive legacy communication strategy, encompassing a legacy report, a dedicated legacy website and a 'FLEET Landing' event designed to communicate and celebrate the Centre's achievements.

The legacy website will be more than simply a repository for FLEET's research and communications outputs. It will also showcase case studies detailing the unique innovations that FLEET has made and how they have impacted the scientific and wider community.

FLEET is also working in 2023 and 2024 to strengthen ties with former members, partners, collaborators and stakeholders, and planning for mechanisms to preserve and enhance this network beyond FLEET's period of performance. The legacy website will be a resource to continue to connect FLEET's network, and we are planning now how to best use other social media networks to foster continued connectivity. FLEET is also featuring its alums heavily in news stories and events to further strengthen the network.

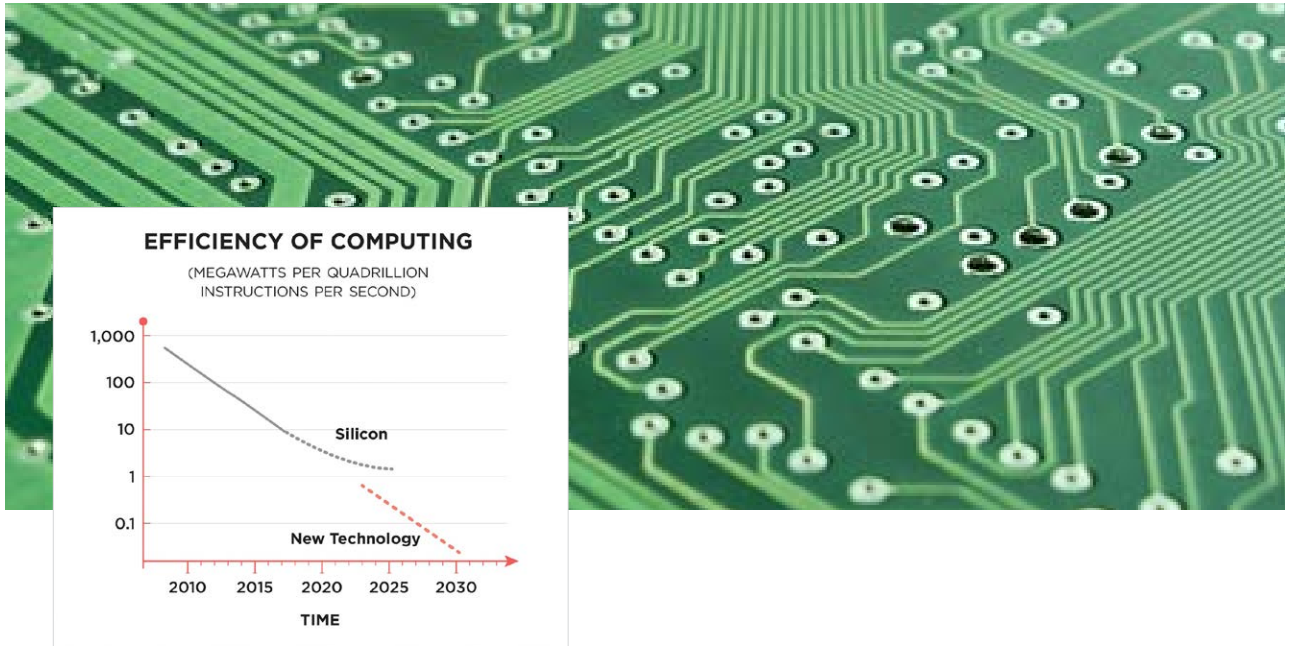
All these efforts are already having an effect: 55% of FLEET's survey respondents see themselves continuing collaborating with FLEET members in the next three years or more.

FLEET'S AREAS OF IMPACT:

- KNOWLEDGE
- SUSTAINABILITY
- CAPACITY
- STEM ED
- INNOVATION
- LEADERSHIP

FLEET's
grand challenge

FLEET's mission has been to enable continuing growth of computing without that growth being throttled by the availability and costs of energy. This will require new transistors that can switch at lower energy.



CHALLENGE: A SUSTAINABLE FUTURE FOR COMPUTING

Computing provides overwhelming benefits to the community and economy. FLEET's mission has been to enable the continuing growth of computing, without that growth being 'throttled' by the availability and costs of energy.

The challenge is to reduce the energy used in information and communication technology (ICT), which already accounts for at least 8% of global electricity consumption and is doubling every decade.

The current, silicon-based technology (CMOS) is 60 years old and reaching the limits of its efficiency.

Fundamental physics tells us that computing efficiency could still be thousands of times better, which inspires us to search for a replacement technology.

Using computers consumes energy. Lots of energy.

Computers work by activating microscopic switches called transistors – a couple of billion of them are packed into each small computer chip.

And each time one of those transistors switches, a tiny amount of energy is burnt.

Consider the billions of transistors in each small computer chip, each switching billions of times a second, and multiply that by hundreds of servers in hundreds of thousands of factory-sized data centres.

For many years, the growing energy demands of computing were kept in check by ever more efficient, and ever more compact computer chips – a trend related to Moore's Law, which observed that the size of transistors halved around every two years.

But Moore's Law is already winding down, and will probably be declared dead in the next decade. There are limited future efficiencies to be found in present technology.

The 2021 SRC Decadal plan for semiconductors identified ever-rising energy demands for computing vs. global energy production as a 'seismic shift' that is creating new risk, and predicted that global computing capacity will be 'strongly limited by energy' in 1-2 decades. The Plan states that new computing paradigms offer opportunities with dramatically improved energy efficiency.

TIMELINE

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

2022 Annual Report

2023 Annual Report

7 US-Aus and EU-Aus colloquia, 17 research seminars, 2 research workshops, 3 conferences, 7 professional & research development events

8 FLEET translation project funded

3 IP & commercialisation focused seminars held

1 industry engagement event – Meet FLEET

CI Torben Daeneke

AI Shao-Yu Chen

AI Peggy Zhang

Future Electronic Materials Research in Aus

Communicating legacy & impact workshop

FLEET 2023 workshop

FLEET-EU conference in Italy

2023 Gordon Godfrey conference

FLEET legacy workshop

4 members trained with Women Leadership Australia

5 Carers grants, 5 Write up scholarships, 3 Women & Diversity in FLEET PhD scholarships and 2 EDI-focused training events offered

HIGHLIGHTS 2023

ASSOCIATE INVESTIGATOR YUERUI LU AWARDED **THE MALCOLM MCINTOSH PRIZE FOR PHYSICAL SCIENTIST OF THE YEAR**

PARTNER INVESTIGATOR FERENC KRAUSZ (MPQ) RECEIVED **THE 2023 NOBEL PRIZE FOR PHYSICS**

3

INVESTIGATORS AWARDED AN ARC LAUREATE, AN ARC INDUSTRY LAUREATE AND AN ARC DECRA FELLOWSHIP

NEW CHIEF INVESTIGATOR STRENGTHENS CAPABILITIES IN FLEET THEMES 1AB AND 2

DIRECTOR MICHAEL FUHRER APPOINTED **FELLOW OF THE AUSTRALIAN ACADEMY OF SCIENCE**

ESTABLISHMENT OF SPIN-OFF COMPANY **TQ TRANSISTORS** TO LICENSE TOPOLOGICAL TRANSISTOR IP DEVELOPED BY FLEET

20

PHD COMPLETIONS

TRAINING EVENTS COLLABORATED WITH OTHER CENTRES OF EXCELLENCE

5

END-USER RELATIONSHIPS ESTABLISHED

25

$2.8M IN COLLABORATIVE INFRASTRUCTURE GRANTS AWARDED TO FLEET RESEARCHERS

PATENT FILED ON METHOD AND CATALYST FOR PRODUCING AMMONIA

Message from the **Director**

2023 is the last full year of FLEET operations, and FLEET will officially end operations on 31 June 2024.

At this stage, FLEET is focused on achieving research milestones that will have a lasting impact beyond the Centre's lifetime. FLEET is also identifying the most promising ideas for near-term impact and enabling researchers to take the next steps in translating those ideas into real-world solutions.

NEW STRATEGIC ACTIVITIES

The FLEET Translation Program (FTP), begun in 2022, finished allocating its total funding of $400,000 in 2023 to a total of 10 translation projects, of which seven have been completed to date.

The aim of the program is to bridge the gap between laboratory research and real-world impact. The program identified researchers in FLEET with the desire and capability to translate their research, and projects with the promise of impact outside the laboratory. Those researchers were equipped with the skills and resources to take the next step towards translation, and they were mentored along the way.

FTP projects are diverse in nature – no two are exactly alike. The end goal may be a prototype or proof-of-principle of a new device, or it may be the demonstration of a potentially valuable service, or open-source software made available to the scientific community.

Two case studies featured in this report show the range of projects and their diverse impacts.

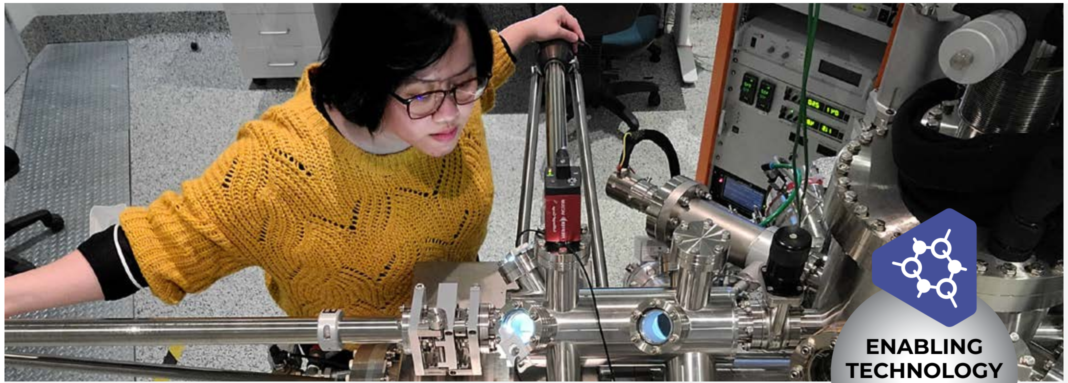
Researchers at Wollongong, Monash, and ANSTO are prototyping and characterising new thermoelectrics built from topological materials (see p31), capitalising on theoretical concepts developed in FLEET.

More-effective thermoelectric materials have the promise to efficiently scavenge waste heat from industrial processes and turn it into useful energy. Researchers at Monash have found a way to automate the tedious task of shaping the metal tip for scanning tunneling microscopy (STM) experiments (see p30), and through FTP support are developing software that may be used by STM labs around the world.

FLEET's translation activities were showcased in the Meet FLEET Industry and Innovation Forum, held on 20 October 2023 at UNSW with around 90 researchers, industry representatives and translation facilitators in attendance. The event included two panel Q&As featuring experts in facilitating innovation and scientists who have successfully translated their research. A poster session featured FLEET researchers and FTP project teams, introducing them to potential industry partners.

TQtransistors.com

A new company, TQ Transistors, has been set up to license the IP of the topological transistor developed at FLEET in 2022. The revolutionary negative capacitance topological quantum field effect transistor (NC-TQFET) is considered capable of surpassing current low-power transistors with an improvement of over 10x in energy efficiency and 2x in switching speed.



ENABLING TECHNOLOGY THEME A

The synthesis and characterisation of novel quantum materials, particularly atomically-thin layered or 'two-dimensional' materials, is a key enabling technology underpinning FLEET research.

In 2023, FLEET research found new ways to control the properties of topological materials. In research overlapping strongly with Theme B (Nanodevice fabrication), ion beams were used to pattern the topological insulator Sb_2Te_3 to create regions of amorphous conventional insulator (with no surface or bulk conduction) in contact with the crystalline topological Sb_2Te_3, with topological conducting edge states at the boundaries between the two. Inducing magnetism in topological insulators can create the quantum anomalous Hall state, in which topological edges carry current in only one direction and are highly protected from resistance. FLEET researchers created a magnetic topological insulator through doping with terbium and, surprisingly, found that the magnetic order is antiferromagnetic, which may be advantageous for certain applications.

FLEET researchers have realised that topological structures of spin or polarisation in real space (so-called topological defects) in materials with ferroelectric or magnetic order can be used to store and manipulate information with extremely low energy. In 2023 FLEET researchers showed that multiferroic materials with both electric and magnetic order can host a range of topological defect structures which can be used to store and manipulate information with the prospects of both electrical and magnetic control. The FLEET team also discovered that the sound from the avalanche-like movements of nanoscale topological defects can be heard through a scanned-probe microscope, giving new insight into the complex dynamics of these objects.

RESEARCH HIGHLIGHTS

FLEET has made significant progress towards key research milestones.

In 2023 FLEET researchers have:

- Used ion beams to pattern a topological material to controllably write conventional insulating regions with conducting topological edges (see p66)
- Observed exciton-polaritons with negative mass in an atomically-thin semiconductor at room temperature (see p54)
- Coherently manipulated the quantum state of excitons in the Floquet-reconstructed bands of an atomically-thin semiconductor under intense light pulses and measured the decoherence due to Floquet states.

FLEET researchers published 94 peer-reviewed articles in 2023, with 48 (51%) in high-impact outlets (IF > 7). Some of the major research achievements are highlighted.

FLEET'S STRATEGIC PRIORITIES

- Enable discoveries at the scientific frontier
- Develop next generation of science leaders
- Establish synergistic partnerships
- Foster equity and diversity in STEM
- Improve students' scientific literacy and public awareness of FLEET science
- Facilitate communication.

ENABLING TECHNOLOGY THEME B

Fabricating new materials into new kinds of devices is also key to FLEET's research program. The inherent layered nature of two-dimensional materials has enabled a revolution in device fabrication through physically transferring layers of material to create stacks, or hetero-structures, of dissimilar layers with properties that would be difficult or impossible to realise in a single material. FLEET has adopted this technique and pushed it forward to create and study new types of hetero-structures and interfaces. In 2023 FLEET researchers showed that thin Ga_2O_3 glass can be printed on top of graphene, where the Ga_2O_3 protects graphene from further processing and also reduces the scattering (and resistance) in graphene due to the optical phonons of the underlying SiO_2 substrate. FLEET also devised a new technique (in work under review) to transfer patterned electrodes of almost any metal, even highly reactive ones, into devices, by transferring the metal from a 'non-stick' diamond substrate. This versatile technique allows the type of metal to be tailored for each device, for example, to optimise the band line-up for two-dimensional semiconductor contacts, without exposing the atomically-thin material to potentially damaging metal evaporation processes. FLEET researchers have also extended hetero-structures to topological materials, showing that films of topological insulator Bi_2Te_3 grown by molecular beam epitaxy can be peeled off the growth substrate and transferred to magnetic and non-magnetic substrates while retaining their topological properties.

ENABLING TECHNOLOGY THEME B
p64

RESEARCH THEME 1
p48

RESEARCH THEME 1

FLEET's Research Theme 1 is creating new transistors in which the topological state of a material is switched on and off. Kagome materials (named for the peculiar interwoven triangular structure of their atomic lattice which is reminiscent of a traditional Japanese basket-weaving pattern) show an interesting interplay of band topology with flat bands, which are capable of hosting very strongly interacting electrons. FLEET has realised that this combination offers unique opportunities to tune the topological band structure and properties of a material. In 2021 FLEET researchers at Monash demonstrated that kagome lattices of metal–organic frameworks can host magnetism driven by strong electron–electron interactions. In 2023 (in work under review) they showed such electronic interactions can be turned on and off by a gate. In 2023 FLEET researchers at RMIT were able to demonstrate the tuning of both superconductivity and the anomalous Hall effect (a topological band property) through proton intercalation of CsV_3Sb_5. These breakthroughs point the way to new types of switches based on correlated electron behaviour in topological materials.

FLEET'S CENTRE PRIORITIES IN 2024

- Communicate FLEET's legacy internally and externally
- Continue implementing the Centre's sustainability and translation plans
- Focus on facilitating on industry mentoring and internship programs.

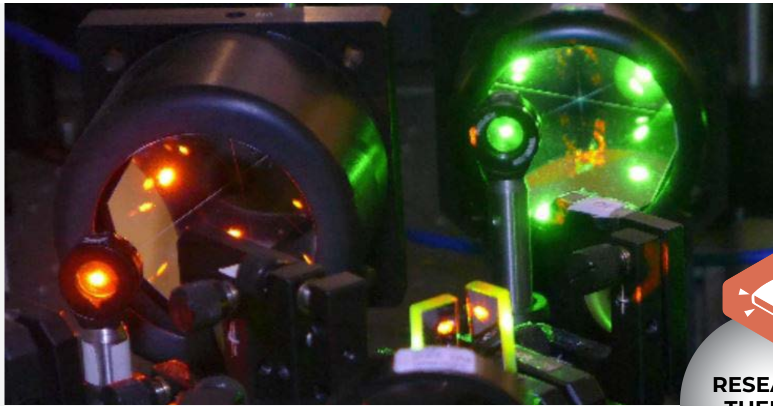
RESEARCH THEME 2

FLEET's Research Theme 2 aims to demonstrate devices based on resistanceless coherent superfluid flow of excitons or exciton-polaritons at room temperature.

A room-temperature superfluid is a grand challenge and requires several advances. Superfluidity requires not only strongly-bound excitons (an electron bound to a hole in a semiconductor) or strongly-coupled exciton-polaritons (excitons strongly coupled to photons in an optical cavity) but also strong interactions between excitons or exciton-polaritons. However, many basic aspects of interparticle interactions were not understood when FLEET began.

In 2023, FLEET researchers made the serendipitous discovery that losses in exciton-polaritons can result in exciton-polaritons behaving as if they have negative mass. The loss of energy to other modes of the system, in this case lattice vibrations or phonons, is generally an unwanted phenomenon. But in this case, the surprising result is that loss can generate a qualitatively new behaviour of the particles in a system. The FLEET team continues to develop the theory of how wave-packets evolve in systems with loss, showing rich topological phenomena that are qualitatively distinct from lossless systems. They also continue to push towards useful exciton-polaritons condensates at room temperature, in 2023 showing that room-temperature condensation was possible in easily-fabricated microcavities containing spin-coated films of perovskite semiconductor.

RESEARCH THEME 2 p52



RESEARCH THEME 3 p56

RESEARCH THEME 3

FLEET's Theme 3 uses light to control the properties of matter on ultra-fast timescales, particularly superfluidity and topology, with prospects for switching materials at the fastest imaginable timescales of hundreds of terahertz. As in Theme 2, many of the basic aspects of superfluids pushed far from equilibrium, or electronic systems driven at ultra-fast timescales, were not understood when FLEET began. Theme 3 research proceeds across a range of platforms from cold-atom superfluids in optical traps to graphene and two-dimensional semiconductors. In 2023 the FLEET team directly observed the Higgs mode (the condensed matter analogue of the Higgs boson in particle physics) of an ultra-cold atomic condensate in the Bardeen-Cooper-Schrieffer (BCS) superfluid state. FLEET researchers also developed a theoretical framework to understand driven dissipative superfluids far from equilibrium. FLEET researchers are striving to use ultra-fast light pulses to push two-dimensional graphene into a topological state. The team also discovered that graphene's optical conductivity in the terahertz is anomalous and reflects the unique vector nature of disorder in the material that has no analogue in conventional semiconductors. FLEET researchers are using fast, intense light pulses to reshape the bands of semiconductors, called Floquet engineering. In 2023, FLEET researchers observed the coherent interactions of real excitons with virtual excitons in the reconstructed Floquet-Bloch bands of a semiconductor driven by a strong light field.

FLEET PATHWAY TO IMPACT 2017–2023

FLEET envisions extending the information technology revolution sustainably into the future through a new, more energy-efficient electronic technology developed in Australia.

To achieve its mission, FLEET has researched new, atomically-thin, electronic materials and new topological physics that will allow transmittal and switching of electrical currents with minimal energy dissipation.

Since its commencement in June 2017, the Centre has made remarkable progress in placing Australia at the forefront of international electronic technology research through the development of the scientific foundation and intellectual property for future low-energy electronic systems.

INPUTS

$35.7M COMMONWEALTH FUNDING

$9.5M CASH INVESTMENT FROM COLLABORATING ORGANISATIONS

$35.6M IN-KIND CONTRIBUTION FROM COLLABORATING ORGANISATIONS

90 INVESTIGATORS

7 EXISTING INFRASTRUCTURES: AUSTRALIAN UNIVERSITIES

18 EXISTING INFRASTRUCTURES: PARTNER ORGANISATIONS

ACTIVITIES

43 POSTDOCTORAL RESEARCHERS BEING TRAINED

56 HIGHER-DEGREE RESEARCH STUDENTS BEING TRAINED

48 WORKSHOPS AND CONFERENCES HOSTED

71 SKILL DEVELOPMENT WORKSHOPS HELD

89 HOME SCIENCE ACTIVITIES DEMONSTRATED

OUTPUTS

627 PUBLICATIONS

10 PATENTS

67 PHD COMPLETIONS

77 POSTDOCTORAL RESEARCHERS TRAINED

1485 RESEARCH PRESENTATIONS GIVEN

1982 MEDIA MENTIONS

OUTCOMES

2 INDUSTRY-FUNDED PROJECTS

3 LINKAGE PROJECTS

SPIN OFF LIQUID METAL PLUS & CO_2 TO GRAPHENE

17,036 CITATIONS

63 FLEET H-INDEX

FLEET TOPOLOGICAL TRANSISTOR IP LICENSED BY SPIN-OFF TQ TRANSISTORS

"TOPOLOGICAL TRANSISTORS" INCL. IN INTERNATIONAL ROADMAP FOR DEVICES AND SYSTEMS – BEYOND CMOS

FLEET MENTIONED IN THE CSIRO 2020 GROWING AUSTRALIA QUANTUM TECHNOLOGY INDUSTRY

FLEET MENTIONED IN THE QUEENSLAND QUANTUM STRATEGY

FLEET'S AREAS OF IMPACT:

KNOWLEDGE
Shaping the scientific community and industry through groundbreaking innovations, technologies and discoveries.

SUSTAINABILITY
Fostering a sustainable future for computing through energy-efficient technologies.

CAPACITY
Nurturing future leaders through training, mentoring and expanding research capabilities, expertise and networks.

STEM ED
Making quantum and science accessible to schools, and fostering community through scientific outreach.

INNOVATION 'beyond the laboratory'.
Fostering creativity and exploring new ideas, encouraging different ways of doing things to create change.

LEADERSHIP
Pioneering a transformative workplace culture marked by inclusivity, family-friendly policies, a strong sense of community, transparency and collaboration.

EQUITY AT FLEET

Making impactful changes to improve diversity in science

FLEET'S AREAS OF IMPACT: (See p15)

CAPACITY INNOVATION LEADERSHIP

- → **KEY DATA**
- → **EQUITY AND DIVERSITY AT FLEET**
- → **SUPPORTING DIVERSITY**

KEY DATA

>31
CULTURAL BACKGROUNDS

5
FLEET WRITE-UP SCHOLARSHIPS OFFERED

3
WOMEN IN FLEET & DIVERSITY IN FLEET SCHOLARSHIPS OFFERED

5
CARERS' GRANTS OFFERED

9HRS
EMPLOYEE ASSISTANCE PROGRAM USAGE (USED BY 4 MEMBERS)

* Note data unavailable: indigenous members, people with disability

Number of women reported includes non-binary members

27%
% WOMEN IN FLEET
58 OUT OF 217 CENTRE MEMBERS

30%
% WOMEN HDR STUDENTS
17 OUT OF 56 HDRS

30%
% WOMEN EARLY CAREER RESEARCHERS
10 OUT OF 33 ECRS

15% — 3
CHIEF INVESTIGATORS
TOTAL 20

13% — 3
PARTNER INVESTIGATORS
TOTAL 23

36% — 14
SCIENTIFIC ASSOCIATE INVESTIGATORS
TOTAL 39

19% — 8
RESEARCH FELLOWS
TOTAL 43

29% — 18
STUDENTS AND RESEARCH ASSOCIATES
TOTAL 62

21% — 4
ADVISORS AND LIAISONS
TOTAL 19

73% — 8
CENTRE BUSINESS TEAM
TOTAL 11

Equity and diversity **at FLEET**

Diverse teams do better science

In 2023, the Centre placed a significant emphasis on the thorough evaluation of the impact of FLEET's equity measures, focusing on the success of the Women in FLEET and Diversity in FLEET fellowships and scholarship.

The ongoing evaluation assesses how fellowship and scholarship awardees have benefited from the support, particularly in terms of their sustained engagement in STEM fields. This initiative aims to understand the long-term impact of the programs and assess factors contributing to recipients' success in STEM.

Also see the case study on p21 collecting feedback from how recipients of Women and Leadership Australia's (WLA's) scholarship have put that training to work.

FLEET has continued to support members whose progress was impacted by COVID with write-up scholarships to enable them to finish off projects and papers. This assistance both ensures project continuity and strengthens their academic records, enhancing their competitiveness for future research opportunities.

These combined efforts underscore FLEET's dedication to fostering talent, adapting to challenges and facilitating impactful contributions to advance STEM disciplines.

FLEET's efforts to support a broader definition of equity than just gender include the Diversity in FLEET scholarships and fellowships and continued science outreach aimed at regional schools (also see the case study on p73 on outreach to regional, majority-indigenous schools in New Zealand).

EQUITY-RELATED TRAINING

To help FLEET members become more aware of issues related to diversity and inclusion, each year every FLEET member must attend at least one training session in equity, diversity and inclusion.

Members may undertake any training and development opportunity of their choice, including face-to-face sessions, webinars and online modules. We believe that letting individuals select training that matches their personal situation and areas of interest will offset some of the 'equity fatigue' that can sometimes accompany mandatory training.

Family-friendly workshops have become a feature of FLEET.

FLEET members participated in the following training related to equity and diversity in 2023:

- Evaluating the impact of equity measures
- How men can support action for gender equity
- Attracting, retaining and progressing neurodivergent talent
- Equal opportunity
- Building knowledge of Australia's First Peoples.

IMPROVING THE VISIBILITY OF WOMEN IN SCIENCE

'You can't be what you can't see.' It has been repeatedly shown that a higher public visibility of women in STEM increases the likelihood that girls will see a viable path for themselves in science.

Mostly due to the efforts of 14 female outreach champions, FLEET outreach in 2023 featured just under 40 individual appearances of women in public-facing events. This meant there was a female presence in almost 80% of public FLEET outreach events.

The benefits of such public visibility are not only confined to girls. A higher awareness of gender diversity in science also has benefits for boys (future allies in the STEM workplace).

In addition, female FLEET members developing and delivering lessons for the John Monash Science School (JMSS) expose those students to a much more diverse cast of physicists than the 'pale, stale and male' bearded, 19th-century gentlemen whose names and biographies are traditionally taught in physics classes.

> "FLEET is going above and beyond when it comes to equity & diversity, and should be a role model for other centres. I learned from FLEETs approach and am applying this in my group.
>
> **FLEET MEMBER**

Dr Tich-Lam Nguyen facilitating 'Reshaping the perceptions of mentoring' panel discussion with Kylie Walker (ATSE) and Dr Francesca Maclean (Laing O'Rourke) at Women in STEMM Leadership Summit

FLEET's legacy will be:

- Incrementally shifted, improved diversity and inclusion in STEM in Australia
- Shared new models for more-inclusive research collaboration.

FLEET's equity measures are already having a positive effect within the Australian science community.

FLEET has a long-standing policy linking financial conference support to gender representation guidelines for committees and invited speakers. In 2023, this has prompted conference organisers to consider these issues, and FLEET has been able to work with them to develop strategies to enable more women to participate.

> "All FLEET members feel that they 'belong' in the Centre, that they are respected and included and that their contributions are valued. The Centre is seen as being a safe place for people to be themselves.
>
> **FLEET MEMBER**

SURVEYING TO EVALUATE IMPACT

Regularly surveying our members has helped FLEET understand the quality and impact of equity and diversity initiatives. In 2023, the survey was distributed for the fifth time, and although the response rate was lower in this final survey (only 20% of active members), 2023 results indicated that of the respondents:

- 94% are aware of the opportunities FLEET is providing to help make it easier to be a woman in STEM
- 94% say they are encouraged to take up career-development opportunities
- 90% agree that FLEET values equity and diversity
- 94% state that flexible working hours are supported at their FLEET node and that outcomes are valued more than physical attendance
- 90% say their node of FLEET provides an inclusive environment for all irrespective of culture, origin, language, age and gender
- 55% see themselves continue collaborating with FLEET members in the next three years or more.

In response to inquiries about the impact of opportunities provided by FLEET on their career development, participants highlighted:

- Opportunities to expand and grow their collaborative network
- Exposure to various career options, many examples and role models with unique career paths around the FLEET network
- Opportunities to access equity and diversity training that have shaped their view of what a good workplace should look like
- Broadened awareness and understanding of available training opportunities.

Members' suggestions to help increase Centre diversity and inclusiveness were broadly aligned with the same areas of impact: more opportunities for expanding collaborative networks, more exposure to diverse career paths, and continuing access to impactful equity and diversity training.

In addition, members suggested continued efforts towards wider definitions of diversity, and encouraging under-represented groups in STEM, both in schools and through recruitment.

Members also suggested a focus on retaining people from underrepresented minorities and ensuring a safe and inclusive work environment.The Centre's five all-member surveys, in addition to targeted interviews with recipients of Women in FLEET and Diversity in FLEET awards and leadership training, will help establish the legacy of FLEET within this important space, and provide valuable data for other Centres of Excellence.

> “I've had opportunities to access equity and diversity training that has shaped my view of what a good workplace should look like.
>
> **FLEET MEMBER**

CASE STUDY

Evaluating the impact of equity initiatives: Women in Leadership

FLEET has provided an environment for early-career women to thrive, progress and grow into capable and confident leaders

A significant cohort of women at FLEET received funding (2019–23) towards high-level leadership training, with surveys of the recipients in 2023 confirming the lasting positive impacts of this training in their new careers.

The leadership program works towards two of FLEET's major strategic aims: to develop the next generation of science leaders and to foster improved equity and diversity in STEM.

18 FLEET women have gone through Women and Leadership Australia (WLA) leadership programs, with the majority subsequently moving on to new roles in which their leadership skills are key.

The Centre has successfully secured five partial scholarships from WLA to support five more FLEET women to participate in the Impact Program in 2024. This aligns with the UN's 2024 International Women's Day theme, 'Count her in: invest in women,

CONTD. p23

“The Leading Edge course had a major component on leading in times of change, which was particularly useful for the then-current Covid-19 situation! In such circumstances, being a good leader or colleague entails understanding how people respond to change, and we were introduced to concepts and models to better understand this and to respond positively.

DR HAREEM KHAN (LEADING EDGE)

Previously FLEET PhD student (RMIT), now Postdoctoral Fellow, CSIRO

“I found the lesson on how to be a good 'coach' (or mentor) particularly useful: e.g. that when providing guidance it's easy to just give advice and opinions, but it's much more useful for the mentee if you help them get to the solution by themselves, as this helps them grow.

DR IOLANDA DI BERNARDO (LEADING EDGE)

Previously a Woman in FLEET Research Fellow (Monash), now Marie Sklodowska-Curie Fellow at IMDEA Nanociencia, Universidad Autónoma de Madrid and a FLEET Scientific Associate Investigator

“The Leading Edge program made me more confident in taking on a more leadership role. Feeling confident in being in such a role, being able to address conflict and being responsible for others. (I just became a team leader two weeks ago.)

DR PEGGY SCHOENHERR (LEADING EDGE)

Previously FLEET Research Fellow (UNSW), now Research Scientist, CSIRO

“Leading Edge helped me appreciate my own strengths and understand how to best utilise communication and critical thinking in leadership to build trust, gain buy-in and achieve outcomes. I learned how to understand team dynamics and individual characteristics to foster a high-functioning team culture. Securing a promotion to department manager within 18 months of completing the program, my transition was assisted by knowledge and skills enhanced by Leading Edge, particularly as a staff supervisor managing a large department as a cohesive, productive unit. I am empowered with confidence for continuous improvement in my leadership skills with the aim of stepping into a more senior role in the future.

TENILLE IBBOTSON (LEADING EDGE)

Previously FLEET Executive Officer, now Department Manager, Monash

“Leading Edge taught me how to understand myself better, manage myself, know others, and work well with others. It gave me tools like good communication and conflict resolution skills, which I find really helpful in my daily workplace. After the program, I saw real changes in my career. I got better at leading, talking to people, and adapting to changes. The program also helped me make new connections, opening up new opportunities for me.

MAEDEHSADAT MOUSAVI (LEADING EDGE), *FLEET PhD student (UNSW)*

“Leading Edge gave me confidence that I have the ability to be an effective leader, allowing me to evaluate my strengths and weaknesses and to consolidate what other people see as an effective leader and then apply that to my own style. The training gave me the confidence to try for new roles even if I don’t strictly fulfil all the key success criteria. And now as a centre manager I use learned people-management techniques to help manage difficult situations.

DR CHARLOTTE HURRY (LEADING EDGE), *Previously FLEET Executive Officer, now Centre Manager, ARC Industry Transformational Training Centre*

“The knowledge I gained in the Impact program in effective listening, negotiating, and prioritising are lifelong guides regardless of what point I am in my career, and aimed to boost productivity without sacrificing my own wellbeing. These skills would be the very framework of how I work and ascend in my chosen career and are pivotal for long-term success.

Already I have reduced stress levels by using Impact’s prioritising skills, and I feel more confident when I negotiate, using learned techniques such as ‘voicing out’.

BIANCA FABRICANTE (IMPACT)

FLEET PhD student (ANU)

accelerate progress'. Investing in women is not just a moral imperative, but also a strategic decision that yields numerous benefits for organisations and society.

FLEET has surveyed WLA graduates to evaluate the ongoing benefits of leadership training, with a few comments pulled out on the previous page.

WLA's Leading Edge program provides practical management and leadership training. It has a holistic approach to building leadership skills and mindset, enabling women to increase resilience and develop invaluable peer-support networks.

The Impact program is aimed at women who wouldn't necessarily consider themselves a leader or who aren't in formal management positions. The 10-week program builds behavioural and interpersonal skills to enable better self-understanding, interpretation, and impact on others.

Scholarships are highly competitive with a limited number of applicants from each organisation eligible to apply.

Efforts to increase the number of women in STEM in leadership positions will also have long-term benefits, as the increased number of women in science leadership in turn become role models to inspire others.

> "Determining my own working style and the working styles/personality types of others was particularly beneficial. In my current role, I consider how to work with different individuals – and am able to manage down and up. Partly thanks to the program, I decided to apply for a different role and am now centre manager at an ARC Training Centre. This was a natural progression in my career path, however, I might not have applied without the impetus of Leading Edge.
>
> **DR DIANNE RUKA (LEADING EDGE)**
>
> *Previously FLEET Education and Outreach Coordinator, now Centre Manager, ARC Training Centre*

> "The outstanding Leading Edge module on professional growth helped me revisit my career path and set a clear path for the future, allowing me to make a clear plan for the next 10 years.
>
> When the opportunity arose I had the confidence to approach the director of a new 2023 Centre of Excellence to register my interest in a role with the centre at a higher level of responsibility in the university HEW scale. If I had not completed the course and set a new career plan, I may not have had the confidence to approach the director to discuss a role with the new centre.
>
> **NICCI COAD (LEADING EDGE)**
>
> *Previously FLEET Node Administrator (RMIT), now Centre Coordinator, ARC Centre of Excellence*

Full comments can be read at FLEET.org.au/leaders2023

Finding sustainable translation opportunities for FLEET science

FLEET'S AREAS OF IMPACT: (See p15)

KNOWLEDGE CAPACITY INNOVATION

- → **KEY DATA**
- → **RESEARCH TRANSLATION**
- → **CASE STUDY:** Meet FLEET industry-and-innovation forum
- → **CASE STUDY:** Automation takes the misery out of scanning microscopy
- → **CASE STUDY:** Turning up the heat on topological thermoelectrics

RESEARCH TRANSLATION

KEY DATA

1
PROVISIONAL PATENT LODGED

23
INDUSTRY BRIEFINGS GIVEN

8
FLEET TRANSLATION PROJECTS FUNDED

$209,300
STRATEGIC FUNDS INVESTED IN TRANSLATION PROJECTS

Research **Translation**

Building links, programs and skills towards translation of research

With a goal to help transform Australia's electronic technologies and utilise research translation opportunities, FLEET has built partnerships and links with research and industry organisations working on novel electronic devices and systems.

Panelists at the Meet FLEET industry-and-innovation forum

FLEET TRANSLATION PROGRAM

The FLEET Translation Program (FTP) is a multifaceted initiative aiming to bridge the gap between research and real-world impact by focusing on three key objectives:

- Encouraging FLEET members who possess both the desire and capability to translate their research into practical applications
- Identifying projects within the FLEET ecosystem that are ripe for translation
- Training FLEET members in essential translation skills, equipping them with the tools and knowledge necessary to navigate the complexities of transforming theoretical knowledge into tangible impact.

FLEET's legacy will be:

- FLEET science translated to industry
- The FLEET research mission continuing beyond the FLEET funding cycle
- Significant numbers of Australia's next generation of science leaders prepared for a wide range of future careers, including industry
- Strong, lasting links between Australian and international science communities.

A program manager, Dr Michael Harvey, was engaged to help FLEET researchers put together their projects. The manager plays a critical role in encouraging researchers to recognise the translational potential of their work and guiding them through the application process.

To support these efforts, $400,000 in strategic funding was allocated for the FTP, along with a deliberately low-barrier application process. This financial investment aimed to remove obstacles and streamline the application process to ensure deserving projects have the opportunity to receive funding and advance their research ideas into concrete outcomes.

2023 HIGHLIGHTS

- Bringing researchers and industry together at the Meet FLEET innovation event (see case study p28)
- Two professional and research development training events
- Eight projects funded – in addition to two projects funded in 2022
- Five completed projects

Since the program began in 2022, the FTP has funded 10 projects, marking a significant step forward in transforming FLEET's advancements into real-world applications:

- TMDC sample manufacturing (RMIT/Swinburne) – completed
- High efficiency zinc battery tech (UNSW) – completed
- Automated scanning tunneling microscope (STM) operation and optimisation (Monash) – funded 2023, completed (see p30)
- Porous thermoelectrics by solution templating (University of Wollongong/ANSTO) – completed (see p31)
- Al_2O_3 barrier layer encapsulant (RMIT) – completed
- Liquid-metal electrode and demo pseudocapacitor (UNSW) – underway
- Switchable coatings (RMIT) – completed
- Ultra-wide range laser locking (Swinburne) – underway

- Compact nitrogen-vacancy magnetometer market exploration (Monash) – completed
- Computational fluid dynamics modelling for blood-flow failure prediction (University of Queensland (UQ) – underway.

The success of the FLEET Translation Program is evident in the initiation of projects that might not have come to fruition through conventional avenues. The FTP provided a platform for FLEET members to actively engage in translation efforts, fostering the development of their capabilities in the process.

The success of the program serves as a testament to the feasibility and benefits of such translation programs, suggesting that other research organisations should consider implementing similar initiatives at an early stage. This way, they can harness the untapped potential within their research communities and expedite the transition from theoretical into tangible real-world impact, fostering a culture of innovation and application.

BETTER FUTURES: A SCIENCE-MEETS-INDUSTRY HACKATHON

The Better Futures Innovation Challenge is a collaborative initiative by five ARC Centres of Excellence: Exciton Science, Engineered Quantum Systems (EQUS), Gravitational Wave Discovery (OzGrav), Transformative Meta-Optical Systems (TMOS) and FLEET.

This inaugural challenge marks a significant milestone, bringing together some of Australia's brightest minds and serving as a platform for the fusion of innovative ideas, diverse skills and individual expertise.

Launched in November 2023, the research hackathon aims to cultivate new collaborations between academic research and the Australian industry, channelling the collective creativity and capabilities of scientists towards addressing real-world challenges and creating tangible impacts for society at large.

Participants of this research hackathon have the opportunity to apply theoretical knowledge and expertise in a practical context. This hands-on experience will not only enhance problem-solving skills but also yield concrete, impactful outcomes.

Additionally, this serves as a valuable asset for enriching participants' CVs, making them more competitive in the job market. The collaborative nature of the event also fosters networking opportunities, enabling participants to connect and collaborate.

BetterFuturesAUS.org

Meet FLEET industry-and-innovation forum

Connecting industry and academia

> I found the poster sessions enjoyable, being able to engage with the researchers and find out more information about their research"
>
> **MEET FLEET INDUSTRY ATTENDEE**

> The panel discussions were helpful in understanding the key challenges to achieve collaboration between industry and academia.
>
> **MEET FLEET ATTENDEE**

An audience of around 90 gathered for the Meet FLEET event at UNSW in October 2023, comprising researchers, industry representatives and others active in the innovation translation ecosystem.

A major aim of the event was to serve as a bridge, fostering connections while giving industry professionals and researchers the opportunity to delve into collaborative research and development programs.

> I gained valuable insights into the operations of the business sector, including their appreciation for the contributions of scientists.
>
> **MEET FLEET ACADEMIC ATTENDEE**

Meet FLEET also showcased the Centre's research capabilities in the realms of quantum and electronic materials and systems, including quantum optics, semiconductor and superconducting devices, sensing, AI, high-tech/deep-tech materials and computing software/hardware of innovative electronics technologies.

FLEET organised the event to foster academia–industry partnerships and provide pathways to explore joint research and development programs, new product innovation and collaborative intellectual property generation.

Over the course of two engaging panel discussions, the audience were introduced to a selection of successful collaborations between academia and industry, witnessing their profound impact not only on the advancement of research and development within their respective fields but also on the broader society.

The first panel featured 'innovation agents' and the second featured 'science-in-industry veterans'.

Innovation agents are those who work at the interface of research and commercialisation, creating links and enabling translation efforts. This panel brought together key enablers of industry–academia collaborations, including university and government agency representatives:

- Hugh Durrant-Whyte (NSW Chief Scientist and Engineer)
- Julie Wheway (AusIndustry / Department of Industry, Science and Resources)
- Fiona Broussard (Monash University)
- Laura Droessler-Dansie (UNSW).

Science-in-industry veterans are those who have navigated the complex landscape of academia–industry collaboration, providing valuable insights gained from their experiences, sharing lessons learned from academia-industry partnerships, the inherent

> “The networking event was exciting as I could meet various FLEET members in person and build a working relationship. I made new connections with some of the industry people who were present.”
>
> **MEET FLEET ATTENDEE**

opportunities, and the barriers that often accompany such engagements. The panel featured:

- Biliana Rajevic (Quantum Brilliance)
- Andrew Dzurak (Diraq)
- Alan Kobussen (Rio Tinto)
- Chris Vale (CSIRO).

The two panels addressed barriers that can hinder research–industry collaborations, including disparities in culture, timelines and expectations, and explored resources and government/academia solutions available to bridge such challenges.

“The dialogue ventured into strategies that both academia and industry can embrace to maintain agility and responsiveness in the ever-evolving quantum landscape,” says FLEET Deputy Director Prof Alex Hamilton (UNSW).

“We hope that the conversations ignited at Meet FLEET will continue to flourish, eventually culminating in partnerships that will significantly shape the future of technology and research,” says FLEET Director Prof Michael Fuhrer.

“As the Centre’s first major FLEET-meets-industry event, Meet FLEET was a huge success,” says FLEET COO Tich-Lam Nguyen. “We want to keep these conversations going and nurture connections that will shape the future of tech and research.”

> The panel discussions cast a spotlight on the most promising domains within quantum applications, including quantum sensing, quantum chemistry, automation, and quantum communication.
>
> **PROF ALEX HAMILTON (UNSW)**
>
> *FLEET Deputy Director*

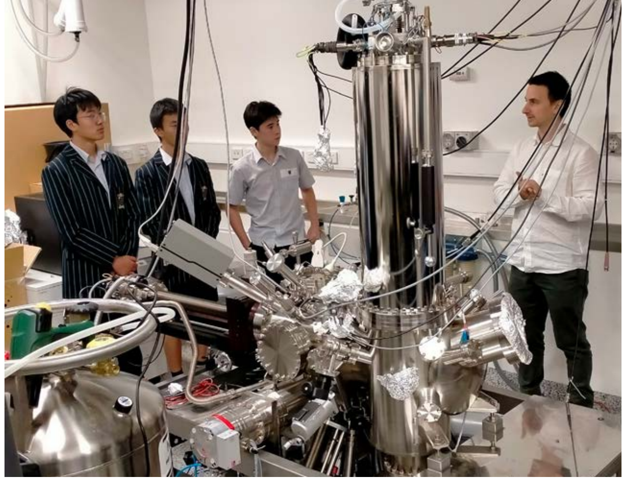
View Meet FLEET poster presentations at FLEET.org.au/meetFLEET

> The poster presentations gave me the chance to interact with the researchers on a more informal basis than is possible during a talk or presentation. Just sad I didn’t get to speak with everyone!”
>
> **MEET FLEET INDUSTRY ATTENDEE**

Automation takes the misery out of scanning microscopy: FLEET Translation Program

CASE STUDY

FLEET Translation Program funding to automate the 'boring parts' of STM experiments, freeing up operators' time



FLEET PhD candidate Julian Ceddia (Monash) received funding from the first round of the FLEET Translation Program to further develop the automation of scanning tunneling microscopes (STMs), based on previous work from the group of his supervisor, Agustin Schiffrin.

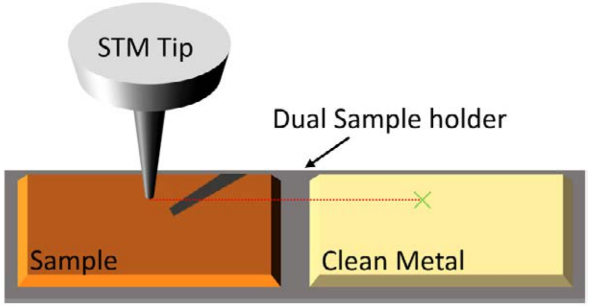
STMs can obtain images of surfaces with atomic-scale resolution by scanning an atomically-sharp probe across the surface of a sample while monitoring an electric current.

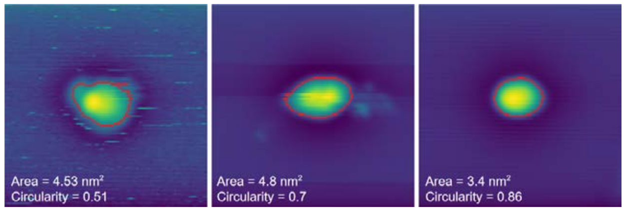
Standard operating practice is that the operator (often a PhD student or postdoc) must sit with the instrument for hours on end, acquiring images every few minutes and surveying a sample to assess its quality or to find a region of interest.

To accomplish this, the STM probe must be conditioned, via a process called 'tip shaping', into a state (e.g. sharp and free of contamination) that is capable of obtaining meaningful data.

"This process is common to all STM experiments and is often very tedious and time consuming, especially when aiming to acquire publication-quality data," says Julian Ceddia.

With funding from FLEET's Translation Program, Julian will develop software to automate the 'boring parts' of STM experiments.





> "I wouldn't have been able to have worked on this project without the FLEET Translation Program and grant, which meant I was given the time to work on the idea without feeling guilty that I should have been doing something else!
>
> **JULIAN CEDDIA**

Julian will use machine learning to analyse STM images to enable automated, informed decision-making in real time. This will free up researchers to sleep at night knowing their sample is being carefully and accurately surveyed, allowing them to go straight to areas of interest in the morning to perform more-complex measurements.

"We hope the software developed through this program will not only benefit STM labs around the world but will be a significant step towards full automation of STM experiments in general," says Agustin Schiffrin.

At the end of 2023, a proof of concept has been completed through the FLEET Translation Program, with the team now testing ideas for the next stage.

FLEET's Translation Project identifies Centre members with the desire and capability to translate their research and shepherds those projects towards commercialisation via funded higher degree by research (HDR) translation stipends, Translation Fellowships and project facilitation funding.

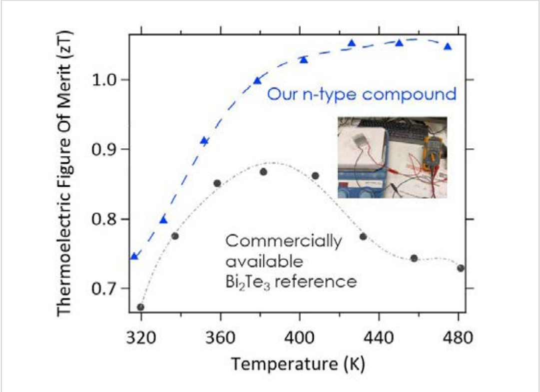
As well as advancing promising projects towards commercialisation, there is very high value in FLEET members getting hands-on experience in the process of such translation projects.

More at FLEET.org.au/scanbot2023

Turning up the heat on topological thermoelectrics: FLEET translation funding towards new chemical synthesis

CASE STUDY

Enhancing topological insulating properties to radically improve thermoelectric performance for future energy harvesting



FLEET funding is supporting the next step in possible translation of thermoelectrics research towards commercialisation in future generators, electronics, vehicles, human-wearable and environmental sensors, and smart electronics.

Thermoelectric materials offer potential solutions to heat-management challenges common to many electronics technologies.

Thermoelectrics are solid-state semiconductors that can convert heat gradients into useful electricity (known as the Seebeck effect). They can also be operated in reverse to generate on-demand cooling from an electric voltage (the Peltier effect).

Thus, they offer great opportunities for future smart devices.

“For example, we might try to recycle the vast amount of heat wasted in numerous processes in society,” says FLEET Associate Scientific Investigator Dr David Cortie (ANSTO/UOW), who is co-leading the project.

“However, traditional thermoelectrics have a low efficiency relative to other energy generation, and to this end they are still mostly used in niche applications, principally in active-cooling systems.

“Interestingly, many of the materials studied within FLEET Theme 1AB (e.g. Bi_2Te_3) are good thermoelectrics and promising topological insulators.”

To date, relationships between these materials’ functionalities has not been extensively explored, with the challenges of scale-up and fabrication of such materials for thermoelectric-scale applications also posing a technical barrier.

FLEET investigators David Cortie, Julie Karel (Monash) and Xiaolin Wang (UOW) received FLEET translation funding to develop a higher-performing thermoelectric material, combining new theoretical concepts developed at FLEET in addition to Discovery Project funding from the Australian Research Council (ARC).

The goal is to leverage topological and thermal transport physics through a custom nanostructure to develop a material that is simultaneously a good electronic conductor and a poor thermal conductor, as these are the requirement for a good thermoelectric.

The team is developing a new chemical synthesis method to make bulk quantities of this material at low cost.

FLEET translation funding allowed the team to source the starting materials and reagent for thermoelectric generators and fund a research associate specialised in chemical synthesis to help develop the new method.

End uses of such technology include portable generators, heat recovery from electronics, harvesting waste heat from vehicles, self-powered human-wearable sensors and environmental sensors. The

technology could become an active component in the next generation of smart electronics.

The possible market is between $450 and $650 million per year. It is expected to grow substantially to 2030 with the rise of the carbon-free economy and growing applications in electronics and electric vehicles.

See more at FLEET.org.au/thermoelectric2023

FLEET'S AREAS OF IMPACT: (See p15)

KNOWLEDGE · CAPACITY · SUSTAINABILITY

INNOVATE

FLEET is pursuing the following research themes to develop systems in which electrical current can flow with near-zero resistance:

- Topological materials
- Exciton superfluids
- Light-transformed materials

The above approaches are enabled by the following technologies:

- Atomically-thin materials
- Nanodevice fabrication

→ **KEY DATA**

→ **FLEET THEMES**

→ TOPOLOGICAL MATERIALS

→ EXCITON SUPERFLUIDS

→ LIGHT-TRANSFORMED MATERIALS

→ ATOMICALLY-THIN MATERIALS

→ NANODEVICE FABRICATION

FLEET RESEARCH CAPABILITIES AND OUTCOMES

20 CHIEF INVESTIGATORS

23 PARTNER INVESTIGATORS

39 SCIENTIFIC ASSOCIATE INVESTIGATORS

39 FTE RESEARCH FELLOWS

57 HIGHER DEGREE RESEARCH (HDR) STUDENTS

$13,190,564

VALUE IN RESEARCH GRANTS AWARDED TO FLEET INVESTIGATORS

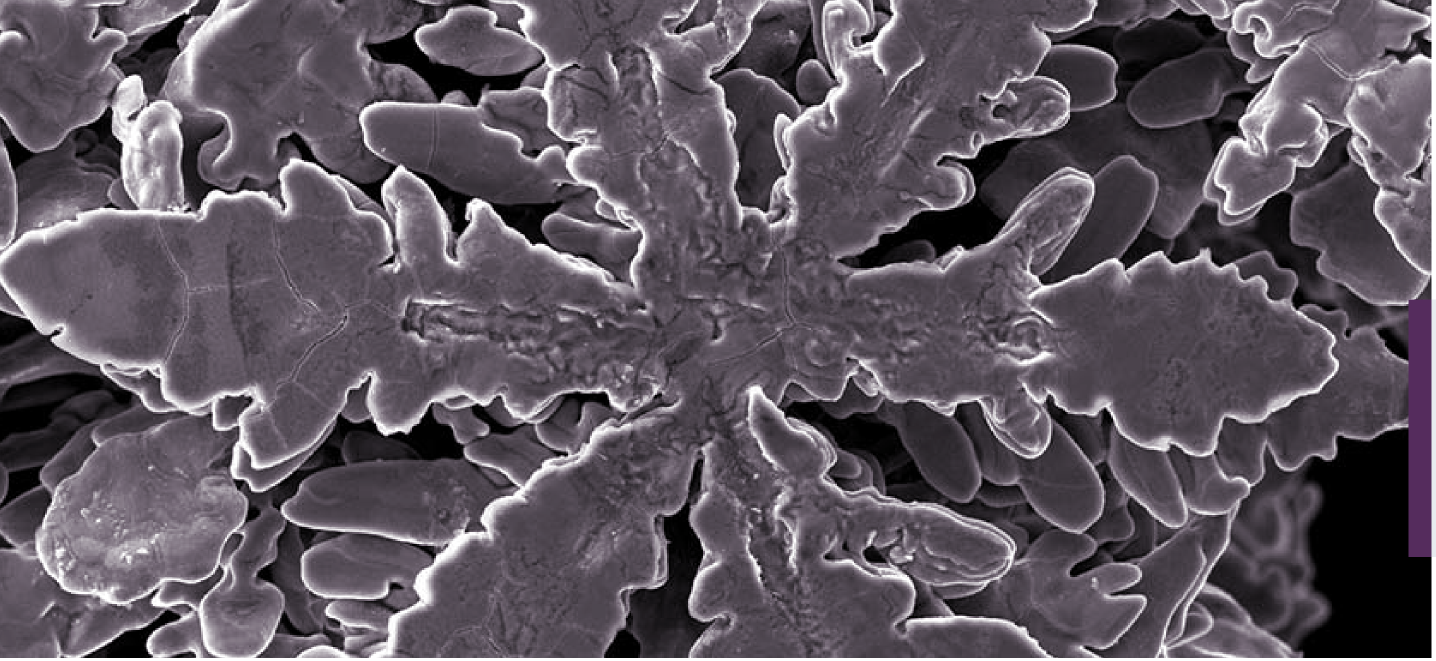
94 PEER REVIEWED JOURNAL PUBLICATIONS

7 ARTICLES WITH IMPACT FACTOR 7-10

46 INVITED PRESENTATIONS AT INTERNATIONAL MEETINGS

41 ARTICLES WITH IMPACT FACTOR > 10

92 PRESENTATIONS TO EXTERNAL SCIENTIFIC COMMUNITY



FLEET themes

FLEET's approach is multidisciplinary, combining efforts across condensed-matter, cold-atom physics, materials science and nanofabrication.

FLEET is pursuing the following research themes to develop systems in which electrical current can flow with near-zero resistance:

RESEARCH THEME 1: TOPOLOGICAL MATERIALS

FLEET's first research theme seeks electrical current flow with near-zero resistance based on a paradigm shift in materials science that yielded 'topological insulators'.

Topological insulators conduct electricity only along their edges, and strictly in one direction, without the 'backscattering' that dissipates energy in conventional electronics.

See more on p48 Theme 1

RESEARCH THEME 2: EXCITON SUPERFLUIDS

FLEET's second research theme uses a quantum state known as a superfluid to achieve electrical current flow with minimal wasted dissipation of energy.

In a superfluid, scattering is prohibited by quantum statistics, so charge carriers can flow without resistance.

Superfluids may be formed by excitons (electrons bound to 'holes').

See more on p52 Theme 2

RESEARCH THEME 3: LIGHT-TRANSFORMED MATERIALS

FLEET's third research theme represents a paradigm shift in material engineering, in which materials are temporarily forced out of equilibrium.

For example, zero-resistance paths for electrical current can be created using short, intense bursts of light, temporarily forcing matter to adopt a new, distinct topological state.

See more on p54 Theme 3

These research approaches are enabled by the following technologies:

ENABLING TECHNOLOGY A: ATOMICALLY THIN MATERIALS

Each of FLEET's three research themes is heavily enabled by the science of novel, atomically-thin, two-dimensional (2D) materials.

These materials can be as thin as just one single layer of atoms, with resulting unusual and useful electronic properties.

To provide these materials FLEET draws on extensive expertise in materials synthesis in Australia and internationally.

See more on p60 Technology A

ENABLING TECHNOLOGY B: NANO DEVICE FABRICATION

FLEET's research sits at the very boundary of what is possible in condensed-matter physics.

At the nano scale, nanofabrication of functioning devices will be key to the Centre's success.

Nano-device fabrication and characterisation links many of FLEET's groups and nodes with diverse fields of expertise such as device fabrication or measurement.

See more on p64 Technology B

FLEET's legacy will be:

- New concepts for low-energy electronics
- Increased fundamental understanding of quantum materials and electronic devices within the global science community
- Improved Australian research capacity for quantum materials, semiconductors and electronic devices
- New discoveries at the scientific frontier.

Chief Investigators

PROF MICHAEL FUHRER, MONASH
Director – FLEET

Michael synthesises and studies new, ultra-thin topological Dirac semimetals and two-dimensional (2D) topological insulators with large bandgaps within Research theme 1, as well as working in themes 2 and 3 and Technology A.

A pioneer of the study of electronic properties of 2D materials, Michael is a Fellow of the American Physics Society, the American Association for the Advancement of Science and the Australian Academy of Science.

ALEX HAMILTON, UNSW

DEPUTY DIRECTOR & LEADER OF RESEARCH THEME 1 – TOPOLOGICAL DISSIPATIONLESS SYSTEMS Alex leads development of new techniques to fabricate and study natural and artificially engineered topological materials. An internationally recognised expert on the properties of electrons and holes in semiconductor nanostructures, Alex is an ARC Industry Laureate Fellow, a UNSW Scientia Professor and a Fellow of the American Physical Society.

AGUSTIN SCHIFFRIN, MONASH

Agustin investigates optically-driven topological phases using ultra-fast photonics, pump-probe spectroscopy and time-resolved scanning probe microscopy within Research themes 1 and 3.

CHRIS VALE, SWINBURNE

Chris synthesises and characterises topological phenomena in 2D, ultracold fermionic atomic gases, investigating new forms of topological matter within Research theme 3.

DIMI CULCER, UNSW

Dimi studies theoretical charge and spin transport in topological materials and artificial graphene with strong spin-orbit coupling within Research theme 1.

ELENA OSTROVSKAYA, ANU

LEADER OF RESEARCH THEME 2 – EXCITONIC DISSIPATIONLESS SYSTEMS

Leading Research theme 2, Elena directs theoretical and experimental research on exciton and exciton-polariton Bose-Einstein condensation and superfluidity near room temperature.

JAN SEIDEL, UNSW

Jan uses scanning probe microscopy (SPM) to study complex oxide materials systems for Research theme 1, and nanoscale SPM patterning in topological materials in Enabling technology B.

JARED COLE, RMIT

Jared applies quantum theory to study electronic transport in nanostructures and the behaviour of topologically-protected conduction channels in electronic devices.

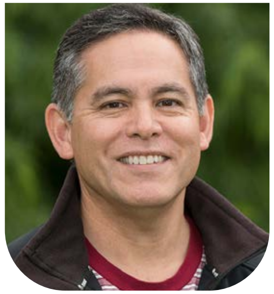
JEFF DAVIS, SWINBURNE

CHAIR OF SPECIAL GOVERNANCE COMMITTEE – EQUITY AND DIVERSITY

Jeff uses femtosecond laser pulses in Swinburne's ultra-fast science facility to modify electronic band structure and realise Floquet topological insulators in 2D materials within Research theme 3.

JULIE KAREL, MONASH

Julie's research at the intersection of materials science and condensed-matter physics applies structural disorder to modify the magnetic and electronic properties of materials, seeking new materials for emerging low-energy nanoelectronic and magnetoelectronic devices.



KRIS HELMERSON, MONASH

LEADER OF RESEARCH THEME 3 – DYNAMICALLY CONTROLLED DISSIPATIONLESS SYSTEMS

Heading Research theme 3, Kris uses ultra-cold atoms in an optical lattice to investigate driven Floquet systems, and topological states in multidimensional extensions of the kicked quantum rotor. Kris is a Fellow of the American Physical Society.

LAN WANG, RMIT

LEADER OF ENABLING TECHNOLOGIES B – DEVICE FABRICATION (until March 2023)

Leading Enabling technology B, Lan also directs study of high-temperature quantum anomalous Hall systems in Research theme 1 and synthesis of novel 2D materials for Enabling technology A.

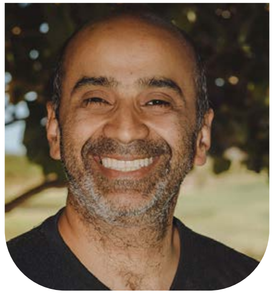
MATTHEW DAVIS, UQ

FLEET TRANSLATION PROGRAM DIRECTOR

Within Research theme 3, Matt studies transitions between novel nonequilibrium states of matter, focusing on relaxation in non-equilibrium and destructive effects of coupling to the environment. Matt is a Fellow of the American Physical Society.

MEERA PARISH, MONASH

Meera develops many-body theories spanning electron-hole systems and ultracold atomic gases. In Research theme 2, she investigates exciton-polariton condensates, while in Research theme 3, she studies non-equilibrium quantum systems such as coupled kicked rotors.



NAGARAJAN 'NAGY' VALANOOR, UNSW

Nagy explores oxides for low-energy electronic devices founded on topological materials in Enabling technology A and synthesises ferroelectric and ferromagnetic materials within Research theme 1.

NIKHIL MEDHEKAR, MONASH

Nikhil investigates the electronic structure of atomically-thin topological insulators and interfaces in Research theme 1 via quantum mechanical simulations on massively-parallel, high-performance computing systems.

OLEG SUSHKOV, UNSW

Oleg leads two theoretical investigations within Research theme 1: artificial nanofabricated materials and laterally-modulated oxide interfaces.

OLEH KLOCHAN, UNSW

LEADER OF ENABLING TECHNOLOGIES B – DEVICE FABRICATION (from April 2023)

Oleh leads the fabrication and measurements of artificially-designed topological insulators using conventional semiconductors in Research theme 1.

PRIYANK KUMAR, UNSW

Priyank designs atomically-thin materials and plasmonic nanostructures for applications in low-energy electronics and optoelectronics. This work fits within both Research theme 3 and Enabling technology A.

TORBEN DAENEKE, RMIT

Torben develops new synthetic approaches for large-scale synthesis of functional, atomically-thin materials with unique electronic, magnetic and optical properties to achieve the goals of FLEET's Enabling technology B, Enabling technology A and Research theme 2.

XIAOLIN WANG, UOW

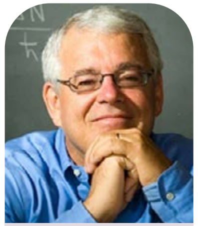
LEADER OF ENABLING TECHNOLOGIES THEME A – ATOMICALLY-THIN MATERIALS

Directing Enabling technology A, Xiaolin investigates charge and spin effects in magnetic topological insulators, and leads synthesis of FLEET's single-crystal bulk and thin-film samples.

Chief Investigators by theme

- RESEARCH THEME 1: TOPOLOGICAL MATERIALS
- RESEARCH THEME 2: EXCITON SUPERFLUIDS
- RESEARCH THEME 3: LIGHT-TRANSFORMED MATERIAL
- ENABLING TECHNOLOGY A: ATOMICALLY THIN MATERIALS
- ENABLING TECHNOLOGY B: NANO DEVICE FABRICATION

Partner Investigators



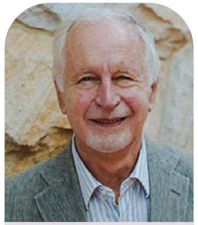
Allan MacDonald
University of Texas

Andrea Perali
University of Camerino

Anton Tadich
Australian Synchrotron

Antonio Castro Neto
National University of Singapore

Barbaros Oezyilmaz
National University of Singapore



David Neilson
University of Camerino

Ferenc Krausz
Max Planck Institute of Quantum Optics

Grzegorz Sek
Wroclaw University of Science and Technology

Ian Spielman
University of Maryland

Johnpierre Paglione
University of Maryland

Justin Hodgkiss
MacDiarmid Institute

Kirrily Rule
ANSTO

Mingliang Tian
High Magnetic Field Lab, Chinese Academy of Science

Nicola Gaston
MacDiarmid Institute

Pu Yu
Tsinghua University

Qi-Kun Xue
Tsinghua University

Shaffique Adam
National University of Singapore

Shuyun Zhou
Tsinghua University

Simon Granville
MacDiarmid Institute

Sven Hoefling
University of Wurzburg

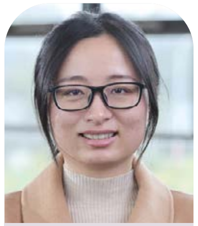
Victor Galitski
University of Maryland

Victor Gurarie
University of Colorado Boulder

William Phillips
University of Maryland

Scientific Associate Investigators


Amgad Rezk
RMIT University


Baoyue Zhang
RMIT University


Bent Weber
Nanyang Technological University Singapore


Catherine Stampfl
University of Sydney


David Cortie
University of Wollongong

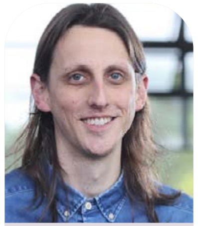

Dmitry Efimkin
Monash University


Dongchen Qi
Queensland University of Technology


Francesca Iacopi
University of Technology Sydney


Golrokh Akhgar
Monash University


Iolanda Di Bernardo
Universidad Autonoma de Madrid


Jackson Smith
RMIT University


Jesper Levinsen
Monash University


Jian-zhen Ou
RMIT University


Jianbo Tang
University of New South Wales


Joanne Etheridge
Monash University


Karen Livesey
University of Newcastle


Karina Hudson
University of New South Wales


Kourosh Kalantar-zadeh
University of Sydney


Laurent Bellaiche
University of Arkansas


Mark Edmonds
Monash University


Matt Reeves
University of Queensland


Michelle Spencer
RMIT University


Nicholas Karpowicz
Max Planck Institute for Quantum Optics


Pankaj Bhalla
SRM University Andhra Pradesh


Pankaj Sharma
University of New South Wales


Peggy Qi Zhang
CSIRO


Qingdong Ou
Monash University

Scientific Associate Investigators

Reza Asgari
University of New South Wales

Sergey Prokhorenko
University of Arkansas

Stefan Maier
Monash University

Sudha Mokkapati
Monash University

Sumeet Walia
RMIT University

Susan Coppersmith
University of New South Wales

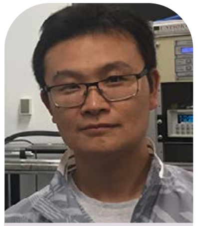
Shao-Yu Chen
National Taiwan University

Tamalika Banerjee
University of Groningen

Yousra Nahas
University of Arkansas

Yuerui (Larry) Lu
Australian National University

Zengji Yue
University of Shanghai for Science and Technology



Zhi Li
University of New South Wales

Research Fellows


Abdulhakim Bake
University of Wollongong


Amelia Dominguez
Monash University


Andrew Groszek
University of Queensland


Anushka Thenuwara
Monash University


Aydin Keser
University of New South Wales


Brendan Mulkerin
Monash University


Cheng Tan
RMIT University


Daisy Qingwen Wang
University of New South Wales


Daniel Moreno Cerrada
Monash University


Daichi Kurebayashi
University of New South Wales


Dawei Zhang
University of New South Wales


Emma Laird
University of Queensland

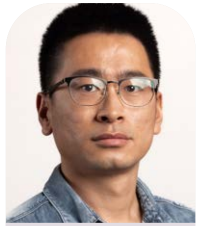

Feixiang Xiang
University of New South Wales


Gary Beane
Monash University


Grace Causer
Monash University


Hong Liu
Monash University


Hongyang Ma
University of New South Wales


Linnan (Leo) Jia
Swinburne University of Technology


Majid Panahendeh Fard
RMIT University


Mateusz Krol
Australian National University


Matthew Edmonds
University of Queensland


Matthew Rendell
University of New South Wales


Mengting Zhao
Monash University


Michael Barson
Monash University


Mitchell Conway
Swinburne University of Technology


Moein Seyfouri
University of New South Wales


Mudassar Nauman
University of New South Wales

Research Fellows


Muhammad Nadeem
University of Wollongong


Olivier Bleu
Monash University


Patjaree Aukarasereenont
RMIT University


Paul Dyke
Swinburne University of Technology


Rhonald Burgos Atencia
University of New South Wales


Sajid Ali
Monash University


Sascha Hoinka
Swinburne University of Technology

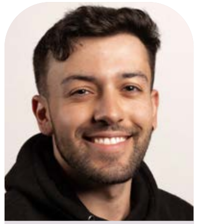

Sultan Albarakati
RMIT University


Tiziana Musso
University of New South Wales

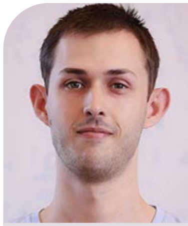

Weiyao Zhao
University of Wollongong


Yahua He
University of Wollongong


Yik Kheng Lee
RMIT University


Yonatan Ashlea Alava
University of New South Wales


Yuefeng Yin
Monash University


Zeb Krix
University of New South Wales


Zhao Liu
Monash University

PhD Students

Abhay Gupta
University of New South Wales

Abhikbrata Sarkar
University of New South Wales

Abigail Goff
RMIT University

Alexander Armstrong
Swinburne University of Technology

Allan Pennings
Swinburne University of Technology

Benjamin Lowe
Monash University

Bianca Fabricante
Australian National University

Caiden Parker
RMIT University

Daniel McEwen
Monash University

Emma Vincent
University of Auckland and RMIT University

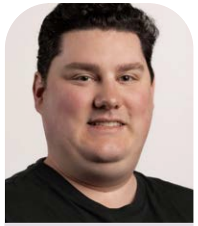
Enamul Haque
Monash University

Gordon Luo
Univeristy of New South Wales

Hongjae Shim
University of New South Wales

Jack Engdahl
University of New South Wales

Jack Muir
Swinburne University of Technology

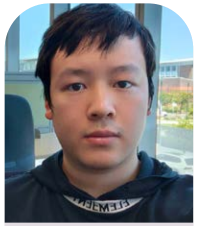


James Blyth
Monash University

Jiuquan Sha
University of Wollongong

Joshua Gray
RMIT University

Julian Ceddia
Monash University



Kaiyu Ma
University of Wollongong

Karen Bayros
RMIT University

Kayla Lord
University of New South Wales

Ke Ri Liang
University of Sydney

Kenneth Choo
Monash University

Krittika Kumar
University of New South Wales

Kwan To Lai
Monash University

Kyle Boschen
Swinburne University of Technology

PhD Students


Liam Watson
Monash University

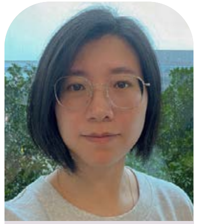

Maedehsadat Mousavi
University of New South Wales


Mahak Chhabra
University of New South Wales


Marcus Goffage
University of New South Wales


Matthew Gebert
Monash University


Md Rezoanur Rahman
University of Wollongong


Mengyun (Molly) You
University of Wollongong

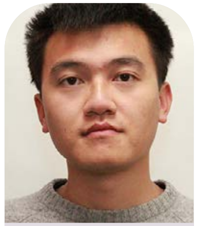

Mitko Oldfield
Monash University

Nam Van Ha
RMIT University


Phat Nguyen
Monash University


Prashant Kumar
RMIT University


Prashanth Kannan
Monash University

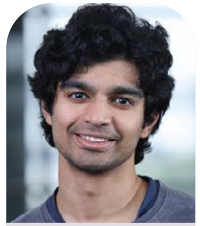

Qile Li
Monash University


Richard Fuchs
University of New South Wales


Rishabh Mishra
Swinburne University of Technology


Ruohan Yu
University of New South Wales


Sajinda Afrin
RMIT University


Sangeet Kumar
Monash University


Sina Gholizadeh
University of New South Wales

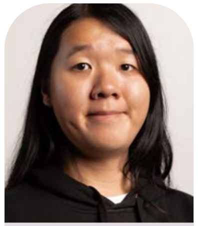

Taylor Christie
Monash University


Tim Edmonds
University of Queensland


Yasufumi Nakano
Monash University


Yogesh Kumar
RMIT University


Yi-Hsun Chen
Monash University


Yow-Ming (Robin) Hu
Australian National University


Yuan Chi
University of New South Wales


Zhanning Wang
University of New South Wales

PhD Students

Ziyuan Zhao
Monash University

Zo Shaw
RMIT University

Honours Students

Benjamin Kalkopf
Monash University

Imogen Stephenson
Monash University

James Brooke
Swinburne University of Technology

Lucas Edwin Glover
University of New South Wales

Matthew Berkman
Swinburne University of Technology

Robert Pellegrino
Australian National University

PROF ALEX HAMILTON

Leader, Research theme 1,
UNSW

Expertise: Semiconductor nanoelectronics and nanofabrication, 2D materials, electronic conduction in nanoscale devices, spin-orbit interactions, behaviour of holes in semiconductor nanostructures

Research outputs (Alex Hamilton)**:**
254 papers
5660+ citations
h-index 38 (Scopus)

"The ambitious goal of Research theme 1 – realising dissipationless transport of electrical current at room temperature and developing novel devices capable of controlling this current – connects scientists from Australia and abroad.

RESEARCH THEME 1

TOPOLOGICAL MATERIALS

FLEET's topological materials research theme has sought to achieve electrical current flow with near-zero resistance, based on a paradigm shift in the understanding of condensed-matter physics and materials science: the advent of topological insulators.

Unlike conventional insulators, which do not conduct electricity at all, topological insulators conduct electricity, but only along their edges.

Along those topological edge paths, electrons can only move in one direction, without the 'backscattering' that dissipates energy in conventional electronics.

Theme 1 researchers' challenge has been to create topological materials that will operate as insulators in their interior and have switchable conduction paths along their edges.

Topological transistors will 'switch', just as a traditional (silicon-based) CMOS transistor does, with a 'controlling' voltage switching the edge paths between being a topological insulator ('on') and a conventional insulator ('off').

For the new technology to become a viable alternative to traditional transistors, the desired properties must be achievable at room temperature (otherwise, more energy is lost in maintaining ultra-low temperatures than is saved by the low-energy switching).

Approaches used are:

- Magnetic topological insulators and quantum anomalous Hall effect (QAHE)
- Topological Dirac semimetals
- Artificial topological systems.

DEFINITIONS

Artificial topological systems Artificial analogues of topological insulators

dissipationless current A flow of particles, such as electrons in an electric current, without wasted dissipation of energy

kagome metal 2D material with a basketlike lattice structure

quantum anomalous Hall effect (QAHE) A quantum effect in which conducting edges carry currents in only one direction and are completely without resistance

spintronics electronics Systems utilising the quantum 'spin' property of electrons (e.g. up or down), in addition to electronic charge (+ or –)

topological state A state of matter defined by the topology of the constituent particles, for example, whether a material is a conventional insulator or a topological insulator

van der Waals (vdW) material A material naturally made of 2D layers, held together by weak van der Waals forces

FLEET.org.au/glossary

DESTROYING CONDUCTIVITY IN A KAGOME METAL

READ OUR CASE STUDY

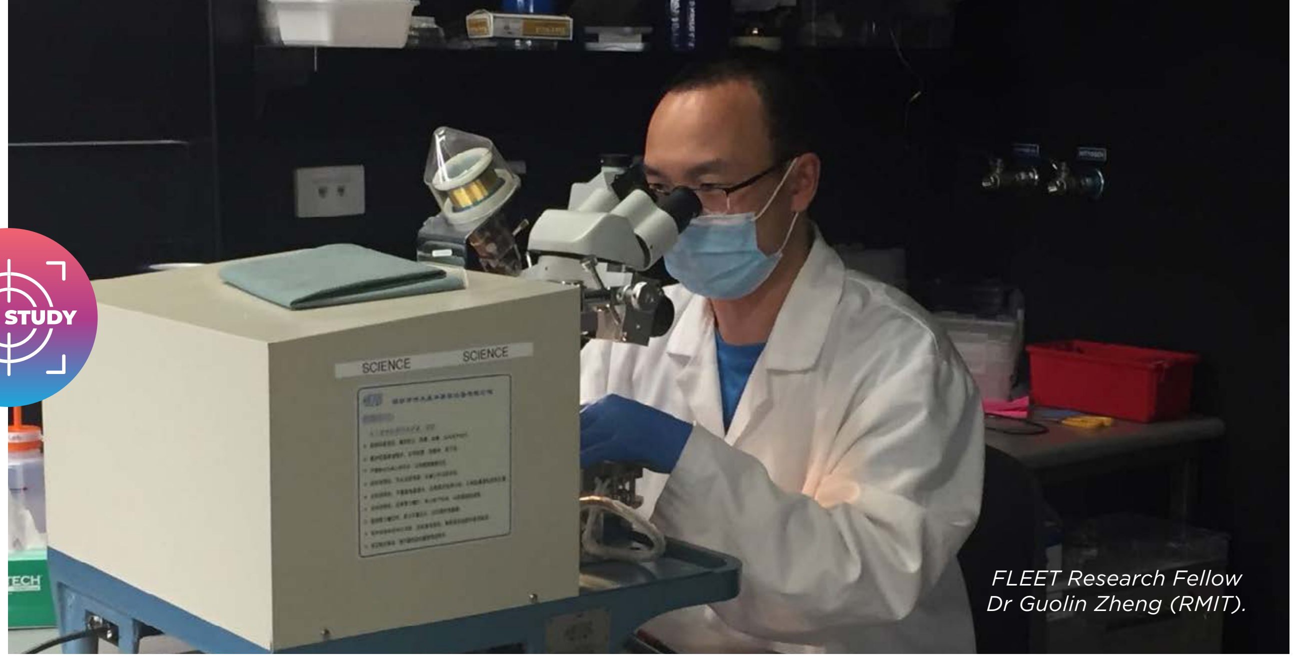
2023 HIGHLIGHTS

- Destroying the superconductivity in a kagome metal (see case study p50)
- Switching polarisation in silicon-compatible metal oxides to create a novel approach to advanced data storage with ferroelectricity
- Automating scanning tunneling microscope optimisation using a new 'bot'
- Fabricating and studying artificial Fermi surfaces, with electronic properties determined by electron-beam surface patterning
- Switching of electron-electron interactions and metal-to-insulator transition in 2D kagome MOF material
- Increasing the phase-coherence length in a porous topological insulator.

Destroying conductivity in a kagome metal

CASE STUDY

Electrically-controlled superconductor-to-‘failed insulator’ transition and giant anomalous Hall effect in the kagome metal CsV_3Sb_5



FLEET Research Fellow Dr Guolin Zheng (RMIT).

An RMIT-led international collaboration published in 2023 uncovered, for the first time, a distinct disorder-driven bosonic superconductor–insulator transition.

The discovery outlines a global picture of the giant anomalous Hall effect and reveals its correlation with the unconventional charge density wave in a recently discovered kagome superconductor metal family, with potential applications in future ultra-low-energy electronics.

Superconductors, which can transmit electricity without energy dissipation, hold great promise for the development of future low-energy electronics technologies. They are already applied in diverse fields such as hover trains and medical magnetic resonance imaging (MRI) machines.

However, precisely how the superconductivity forms and works in many materials remains an unsolved issue and limits its applications.

Recently, a new kagome superconductor family termed AV_3Sb_5 has attracted intensive interest for their novel properties. (‘Kagome’ materials feature an unusual lattice named for a Japanese basket-weave pattern with corner-sharing triangles, and the A in AV_3Sb_5 refers to caesium, rubidium, or potassium.)

Although quantum phenomena accessible in AV_3Sb_5materials provide ideal platforms for physics studies such as topology and strong correlations, the origin of these material’s giant anomalous Hall effect and superconductivity have remained unexplained, despite many recent investigations.

The FLEET-led collaboration of researchers at RMIT University and partner organisation the High Magnetic Field Laboratory (China) confirmed for the first time the electric control of superconductivity and anomalous Hall effect (AHE) in the van der Waals (vdW) kagome metal CsV_3Sb_5.

The key was manipulating the giant AHE via reversible proton intercalation.

“We wanted to see if we could achieve similar success as our trials using the proton gate technique in vdW spintronic devices, which effectively modulated similar carrier densities,” says first author, FLEET Research Fellow Dr Guolin Zheng (RMIT).

“The ability to tune the carrier density and the corresponding Fermi surfaces would play a vital role in understanding and manipulating these novel quantum states and would potentially realise some exotic quantum phase transitions.”

The team chose to test this theory on CsV_3Sb_5 devices, easily designed and fabricated based on the FLEET team’s rich experience in this field.

With thinner flakes, around 40 nanometres, the injection of the proton became quite easy, as well as being highly reversible. “Indeed, we have seldom met such a proton-friendly material!” says co-first author, FLEET Research Fellow Dr Cheng Tan (RMIT).

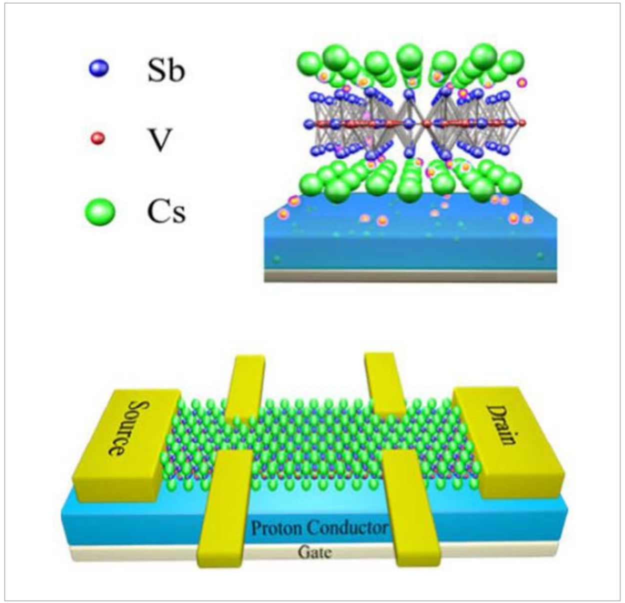
The unique coexistence of electronic correlations and band topology in AV_3Sb_5 materials allows investigation of intriguing transitions of these correlated states, such as superconductor-to-insulator transition, a quantum phase transition usually tuned by disorders, magnetic fields and electric gating.

The team's further explorations of these potential quantum phase transitions met with success, but they were surprised to observe that the critical temperature of the phase shift decreased, showing a clear superconductor-to-insulator transition under increasing proton injection.

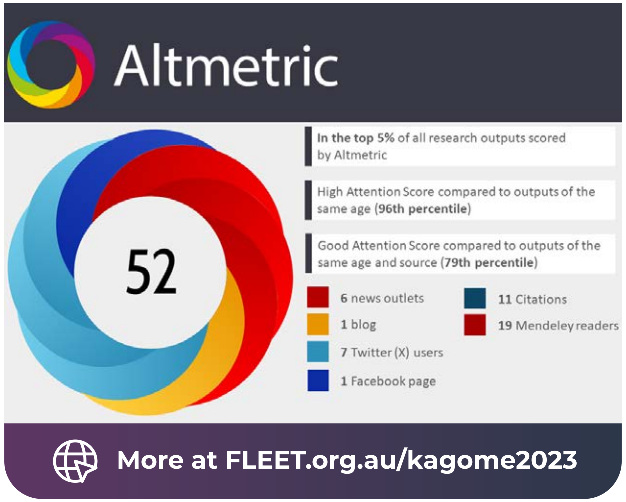
"Proton intercalation introduced disorder and suppressed both charge density wave and superconducting phase coherence," says contributing-author A/Prof Lan Wang (also at RMIT). "And this gave rise to a superconductor–insulator transition associated with localised Cooper pairs and higher electrical resistance, dubbed a 'failed insulator'".

This discovery of a distinct, disorder-driven bosonic superconductor–insulator transition outlines a global picture of giant AHE and reveals its correlation with the well-known unconventional charge density wave in the CsV_3Sb_5 family.

"This significant and electrically-controlled superconductor–insulator transition and anomalous Hall effect in kagome metals should inspire more investigations of the relevant intriguing physics, with promise for energy-saving nanoelectronic devices," says Lan.



Left: The proton-gating device fabricated at RMIT, CsV_3Sb_5 nanoflake above and Hall-bar device below



COLLABORATING FLEET PERSONNEL:

Research Fellow Guolin Zheng *RMIT*

Research Fellow Cheng Tan *RMIT*

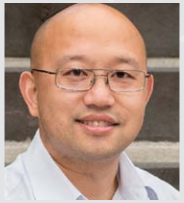
PhD student Sultan Albarakati *RMIT*

PhD student Meri Algarni *RMIT alum*

PhD student Lawrence Farrar *RMIT*

Partner Investigator Mingliang Tian *China High Magnetic Field Laboratory*

Chief Investigator Michael Fuhrer *Monash*



Chief Investigator Lan Wang *RMIT*

This research relates to FLEET milestones M1.6 and M1.7. See page 13 of FLEET's Strategic Plan at FLEET.org.au/strategic-plan

The study was published in *Nature Communications* in February 2023.

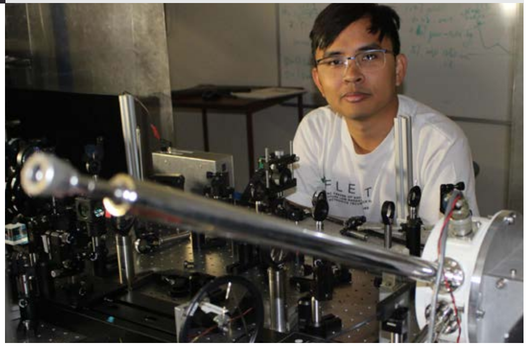
PROF ELENA OSTROVSKAYA

Leader, Research theme 2
ANU

Expertise: non-linear physics, quantum degenerate gases, Bose-Einstein condensates, exciton-polaritons

Research outputs (Elena Ostrovskaya):
156 papers
5810+ citations
h-index 40 (Scopus)

"Before FLEET, only a couple of people in Australia knew about exciton-polaritons! We've built up a scientific community in this field in the last few years.



RESEARCH THEME 2

EXCITON SUPERFLUIDS

FLEET's second research theme uses a quantum state known as a superfluid to achieve electrical current flow with minimal wasted dissipation of energy.

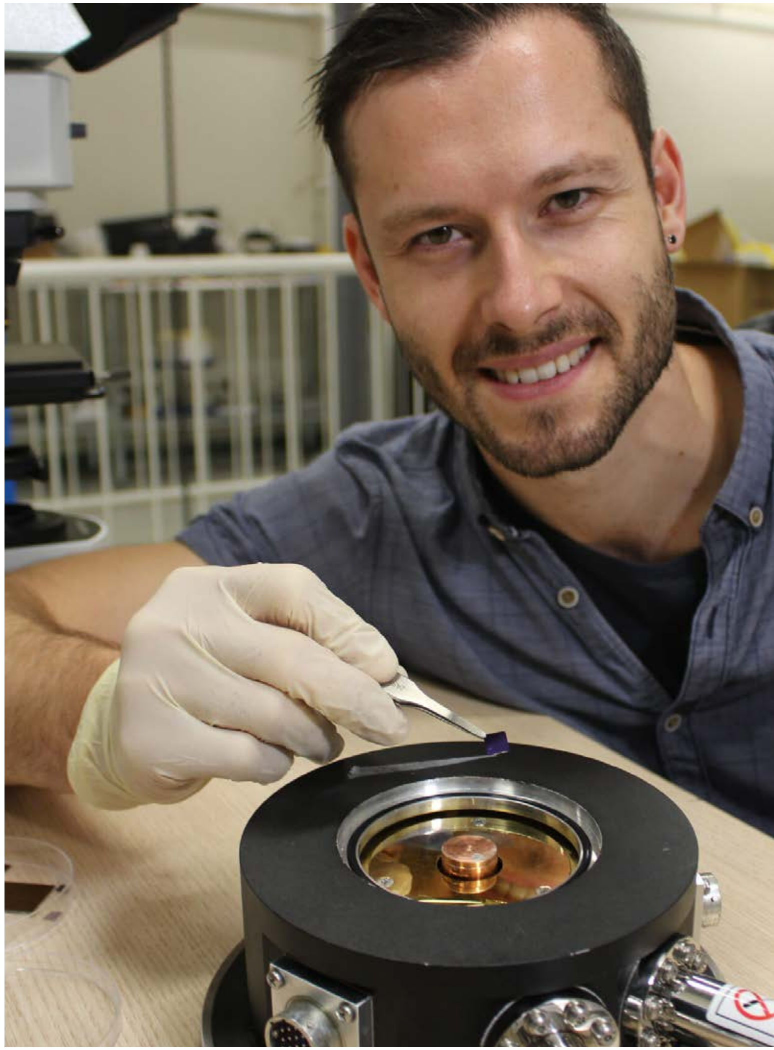
In a superfluid, scattering is prohibited by quantum statistics, so electrical current can flow without resistance.

A superfluid is a quantum state in which all particles flow with the same momentum, and no energy is lost to other motion. Particles and quasi-particles, including both excitons and exciton-polaritons, can form a superfluid.

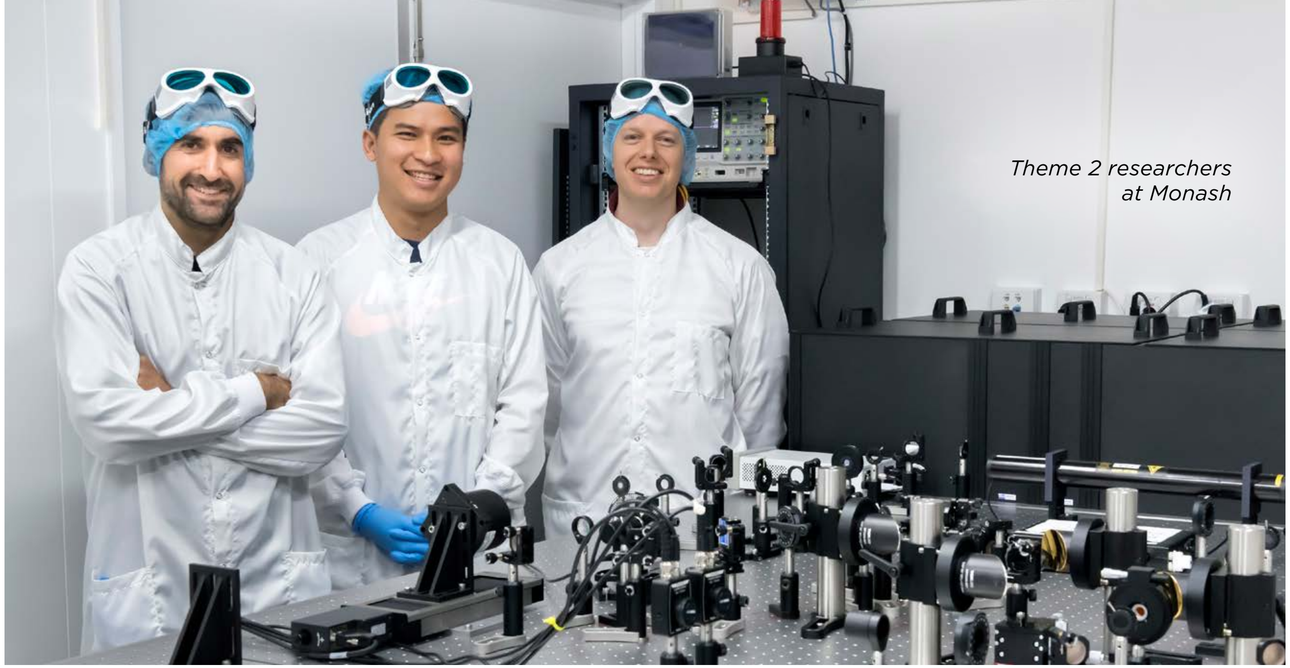
Researchers have sought to create superfluid flows using three approaches:

- Exciton-polariton bosonic condensation in atomically-thin materials
- Topologically-protected exciton-polariton flow
- Exciton superfluids in twin-layer materials.

If exciton-superfluid devices are to be a viable, low-energy alternative to conventional electronic devices, they must be able to operate at room temperature, without energy-intensive cooling. Thus, FLEET has sought to achieve superfluid flow at room temperature, using atomically-thin semiconductors as the medium for the superfluid.



Left and right: members of the Research theme 2 team at ANU



Theme 2 researchers at Monash

HYBRID PARTICLES SURPRISE WITH NEGATIVE MASS

READ OUR CASE STUDY

2023 HIGHLIGHTS

- Discovering that phonons can cause dissipative light–matter coupling in TMDCs, resulting in exciton-polaritons with negative mass (see case study p54)
- Developing theories for modelling optical response of optically-active materials such as 2D TMDCs and van der Waals hetero-structures
- Theoretically exploring the dynamics of wavepackets in non-Hermitian exciton-polariton systems.

DEFINITIONS

exciton Quasi-particle formed of two strongly-bound charged particles: an electron and a 'hole'

Exciton-polariton Part matter and part light quasi-particle: an exciton bound to a photon

heterostructure A structure made by stacking layers of different semi-conducting materials

microcavity A micrometre-scale structure; an optical medium sandwiched between ultra-reflective mirrors, used to confine light such that it forms exciton-polaritons

superfluid A quantum state in which particles flow without encountering any resistance to their motion; both excitons and exciton-polaritons can form a superfluid state

transition metal dichalcogenide crystals (TMDCs) Atomically-thin materials that are excellent hosts for excitons, hosting excitons that are stable at room temperature and interact strongly with light

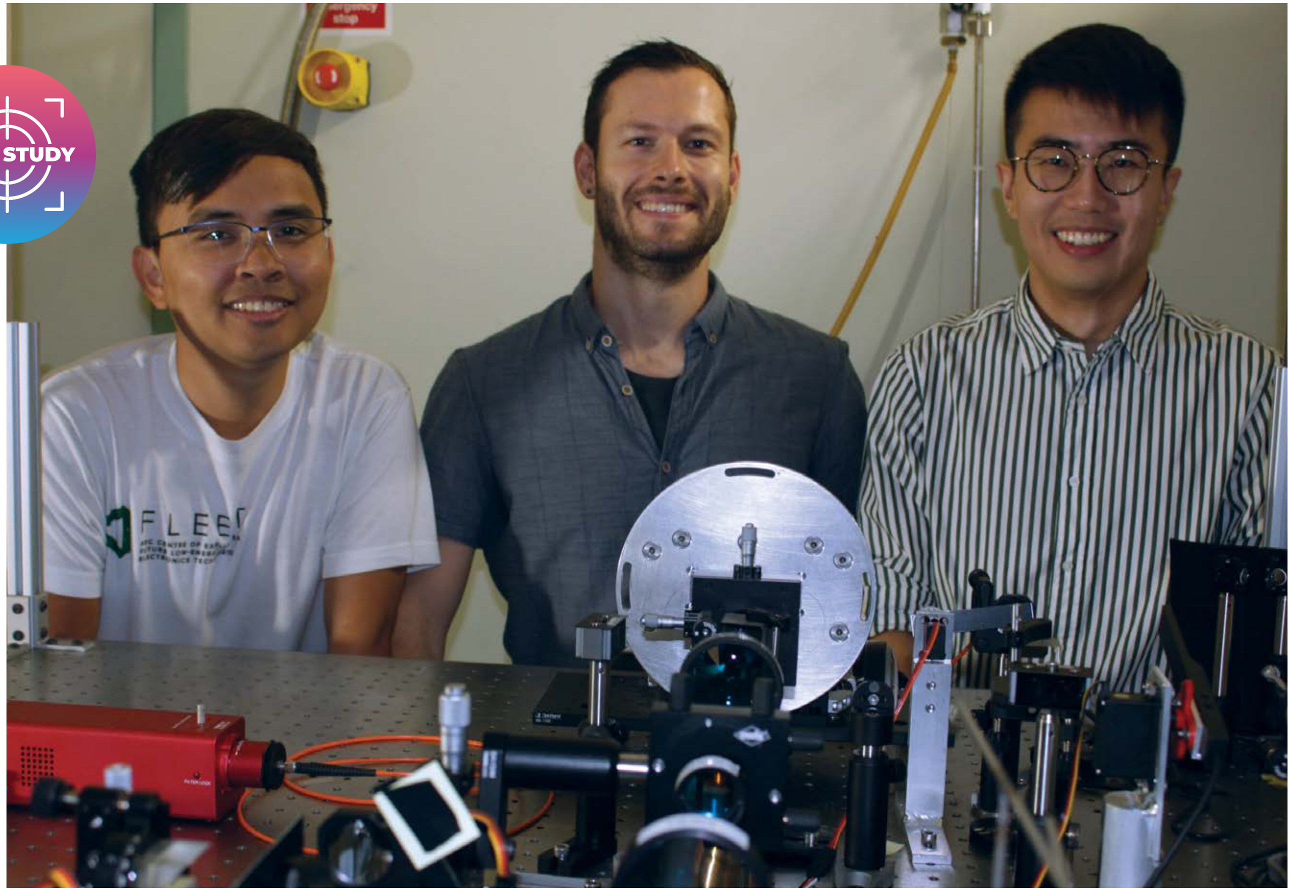
van der Waals (vdW) material A material naturally made of 2D layers, held together by weak van der Waals forces

FLEET.org.au/glossary

Hybrid particles surprise with negative mass

Unlocking counterintuitive exciton-polariton behaviours to probe new physics towards possible future quantum devices

A surprise observation of negative mass in exciton-polaritons has added yet another dimension of weirdness to these strange light–matter hybrid particles.



The ANU research team from left: Dr Eliezer Estrecho, Dr Matthias Wurdack and Dr Tinghe Yun

The experiments with exciton-polaritons carried out by Dr Matthias Wurdack, Dr Tinghe Yun and Dr Eliezer Estrecho, revealed that under certain conditions the dispersion became inverted – equating to a negative mass.

To add to the surprise, the unexpected cause has turned out to be losses.

"We did not expect that – the dispersion followed very unconventional behaviour," said Matthias.

An exciton is formed from an electron and a hole pairing up in a semiconducting crystal. If this pair then strongly couples to a photon, a hybrid particle known as an exciton-polariton can form.

Exciton-polaritons were first observed more than 30 years ago and have been shown to exhibit remarkable properties, including superfluidity and formation of Bose-Einstein condensates. Around the world a number of research groups are exploring the counterintuitive behaviour of these strange particles in the hope they could underpin future low-energy technologies.

The observation of negative mass sent the scientists, from the group of Prof Elena Ostrovskaya, back to the whiteboard to try to work out what could cause such an effect.

The simplicity of the experiment, a monolayer of tungsten disulfide integrated in a microcavity, meant that it could be approximated with a simple coupled-oscillator model and so left few possibilities for unexpected effects. The team soon realised an imaginary coupling constant, called dissipative coupling, in their calculations replicated their observations.

However, they struggled to make sense of the mathematical model until they looked at other fields, such as microwave cavities, and realised that an imaginary coupling constant could equate to losses from the light–matter system.

To confirm that interpretation, the team reached out to experts in numerical modelling of physics in 2D systems at the Technical University of Berlin in Germany. These experts confirmed that the negative mass could arise from losses – specifically due to interactions between exciton-polaritons and phonons in the atomically-thin semiconductor.

Calculations also showed that, as the exciton-phonon interactions were turned off, the mass went from positive to negative, behaviour that subsequent experiments at ANU reproduced.

Matthias likened the behaviour of exciton-polaritons to that of boats on a lake.

“The phonons in the active material are like waves on the lake which can affect the movement of the boats – redirecting them, causing them to sway and capsize. This reduces their kinetic energies, which overall leads to losses in momentum, energy and occupation numbers,” he said.

In the quest for low-energy technology, scientists go to great lengths to reduce or remove losses, said Eliezer, also from FLEET.

“Typically, we don’t want losses, but here losses have given us something new,” he said.

“It enabled us to introduce a negative mass to the strongly-coupled system.”

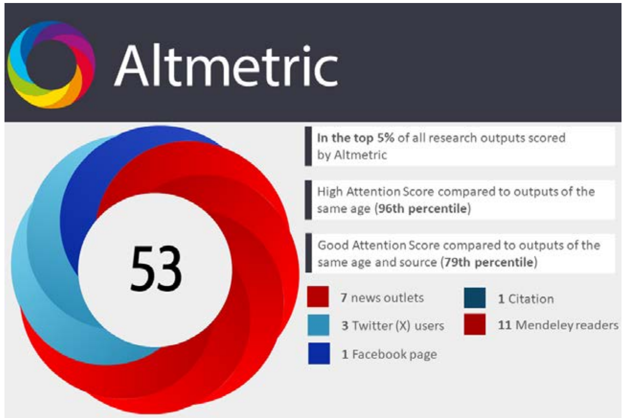
The discovery is another facet of exciton-polaritons’ counterintuitive behaviour, Matthias said.

“This behaviour could be used for dispersion engineering, potentially to probe new physics and create as yet undreamed-of devices.”

“I cannot predict the extent of future applications yet using this kind of dispersion engineering, but I am hopeful this will be explored in future research activities,” he said.

Story first published:

Australian National University



More at FLEET.org.au/negative2023

COLLABORATING FLEET PERSONNEL:

Research Fellow Matthias Wurdack
ANU

PhD student Tinghe Yun
Monash alum

Research Fellow Eliezer Estrecho
ANU

Chief Investigator Elena Ostrovskaya
ANU

This research relates to FLEET milestones M2.2.1 and M2.2.4. See page 13 of FLEET’s Strategic Plan at FLEET.org.au/strategic-plan

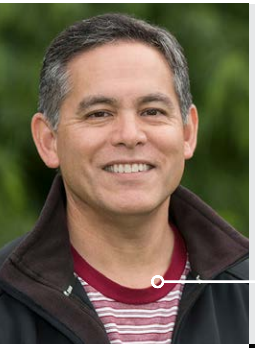
The study was published in *Nature Communications* in February 2023.

PROF KRIS HELMERSON

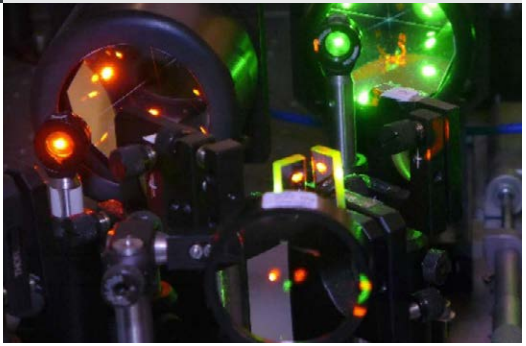
Leader, Research theme 3
Monash

Expertise: ultra-cold collisions of atoms, matter–wave optics, non-linear atoms dynamics, atomic gas superfluidity, atomtronics, non-linear atom optics

Research outputs (Kris Helmerson):
120 papers
5860+ citations
h-index 35 (Scopus)



"The ability to use light to modify electron conduction in materials opens up new possibilities in high-speed, low-dissipation electronics.



RESEARCH THEME 3

LIGHT-TRANSFORMED MATERIALS

FLEET's third research theme represents a paradigm shift in material engineering, in which materials are temporarily forced out of equilibrium.

The zero resistance paths for electrical current sought at FLEET can be created using two non-equilibrium mechanisms:

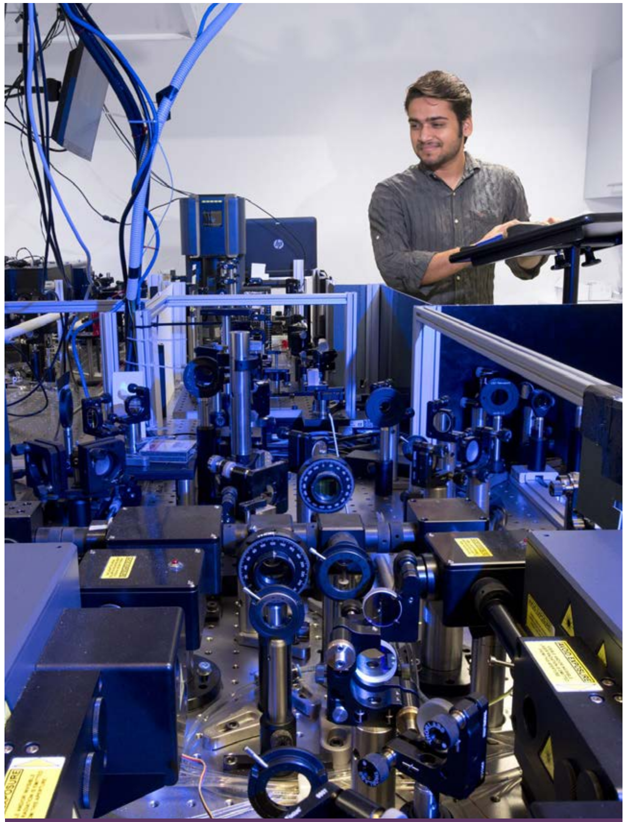
- Short (femtosecond), intense bursts of light temporarily forcing matter to adopt a new, distinct topological state.
- Dynamically-engineered dissipationless transport.

Very short, intense pulses of light are used to force materials to become topological insulators (see Research theme 1 page 48) or to shift into a superfluid state (see Research theme 2 page 52).

The forced state achieved is only temporary, but researchers learn an enormous amount about the fundamental physics of topological insulators and superfluids as they observe the material shifting between natural and forced states over a period of several microseconds.

By using ultra-short pulses to switch between the dissipationless-conducting and normal states, we can also create ultra-fast opto-electronic switching of this dissipationless current.

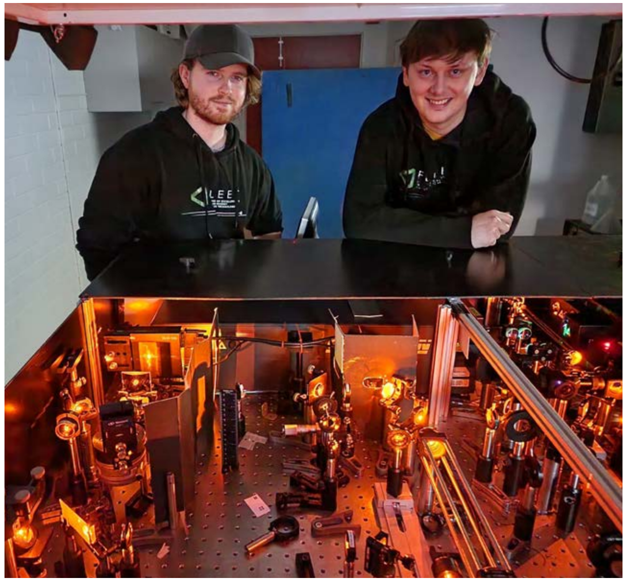
The second approach typically uses periodic perturbations (usually, optical) to modify the time-averaged behaviour of the system.

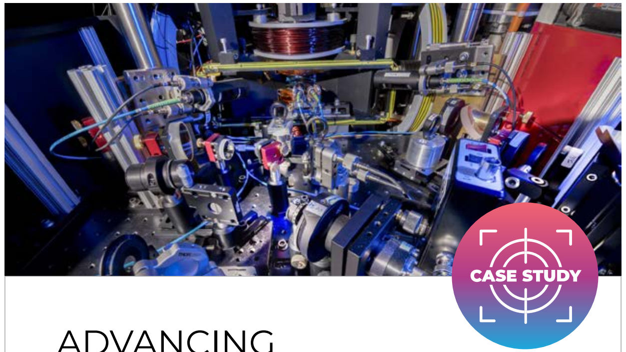


FLEET is the first and the only team to have made a hybrid condensate at cryogenic temperature

2023 HIGHLIGHTS

- Advancing quantum interaction understanding in 2D semiconductors (see case study p58)
- Measuring interactions between virtual excitations in driven Floquet Bloch bands and real excitons, leading to decoherence of the otherwise adiabatic process
- Using terahertz time-domain spectroscopy to measure and study complex dynamic conductivity in electrostatically-gated graphene across Drude to non-Drude regimes
- Directly observing amplitude oscillations in ultra-cold atomic BCS condensate with resonant interactions corresponding to Higgs mode collective excitation
- Investigating behaviour of a mobile spin-½ impurity atom immersed in a Fermi gas, where the interacting spin–up and non-interacting spin–down states of the impurity are Rabi coupled via an external field
- Developing a new model to describe non-equilibrium dynamics leading to steady states of a driven dissipative superfluid.





ADVANCING QUANTUM INTERACTION UNDERSTANDING IN 2D SEMICONDUCTORS

READ OUR CASE STUDY

DEFINITIONS

Bardeen-Cooper-Schrieffer (BCS) regime Superconducting state by formation of electron pairs

dissipationless current A flow of particles, such as electrons in an electric current, without wasted dissipation of energy

electrostatically-gated material A material that can be switched from conductive to non-conductive state by application of voltage

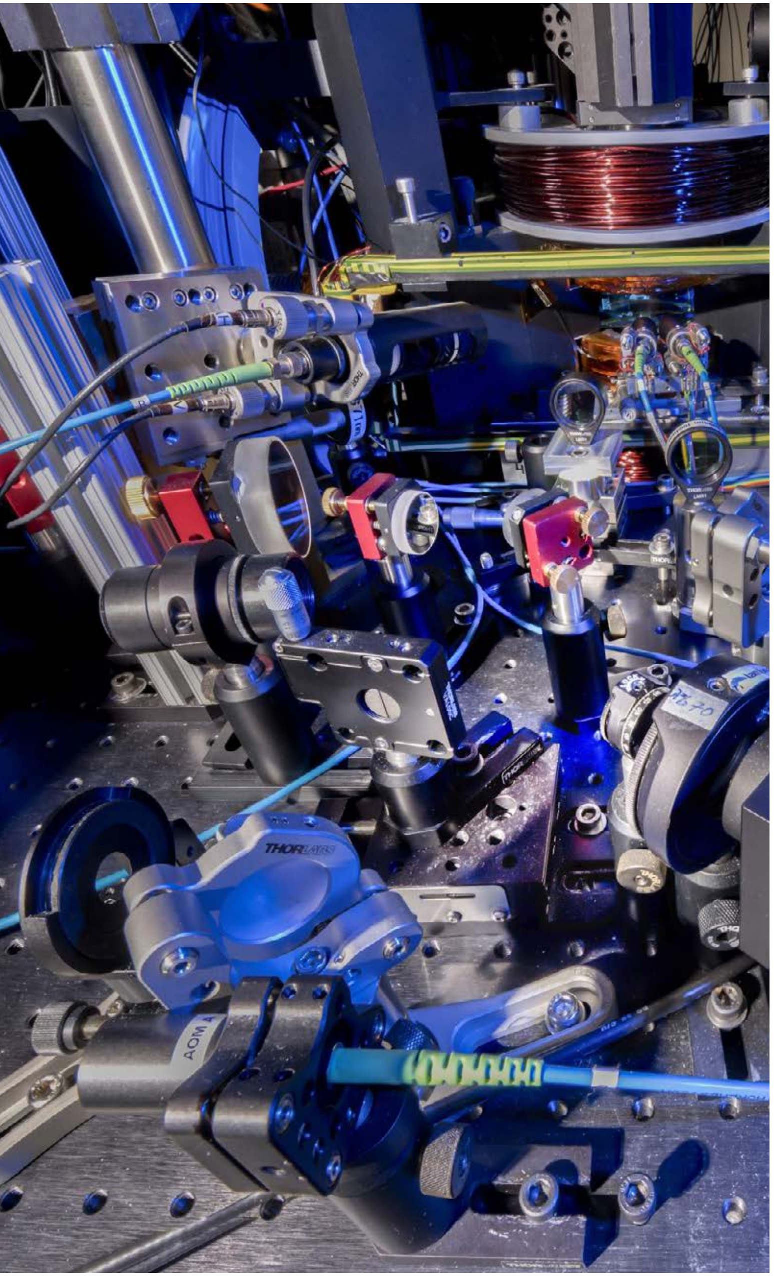
Fermi gas An easily-controlled gas comprising non-interacting fermions (e.g. electrons, neutrons, protons)

Floquet topological insulator A topological insulator created by applying light to a conventional insulator

non-equilibrium state A state temporarily forced by the application of energy, such as light

terahertz spectroscopy Using light with a frequency measured in trillions of Hertz (cycles per second)

FLEET.org.au/glossary



Advancing quantum interaction understanding in 2D semiconductors

CASE STUDY

Unlocking fresh insights into the behaviour of quantum impurities within materials

An international theoretical study led by Monash University researchers introduced a novel approach known as 'quantum virial expansion' – a powerful tool to uncover the complex quantum interactions in 2D semiconductors.

This breakthrough holds potential to reshape our understanding of complex quantum systems and unlock exciting future applications utilising novel 2D materials.

The study of 'quantum impurities' has far-reaching applications across physics in systems as diverse as electrons in a crystal lattice and protons in neutron stars. These impurities can collectively form new quasi-particles with modified properties, essentially behaving as free particles.

The new technique shows remarkably good agreement with experimental results, essentially perfect at high temperature with small discrepancies at lower temperatures.

Although a straightforward many-body problem to state, quantum impurity problems are difficult to solve.

"The challenge lies in accurately describing the modified properties of the new quasi-particles," says Dr Brendan Mulkerin (Monash), who led the collaboration with researchers in Spain.

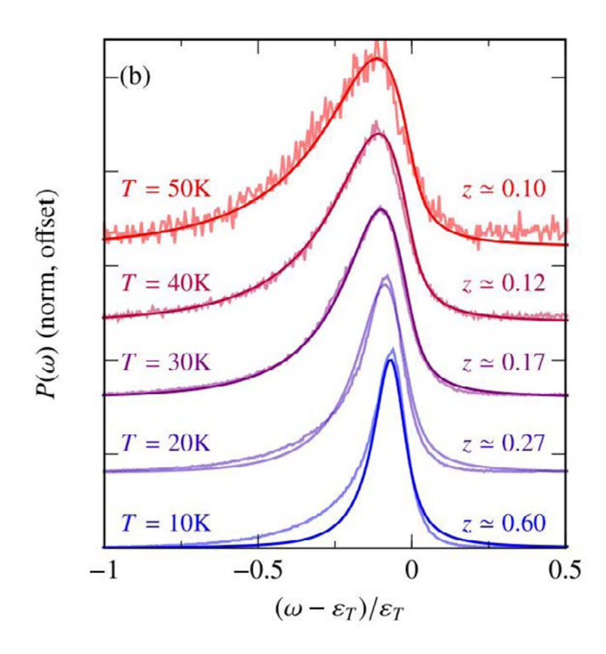
The study offers a novel perspective on exciton-polarons as impurities in 2D materials – bound electron-hole pairs immersed in a fermionic medium.

As a solution to the problem, the Monash team introduced the 'quantum virial expansion' (QVE), a powerful method that has long been indispensable in ultra-cold quantum gases.

In this case, integrating QVE into the study of quantum impurities meant that only the interactions between pairs of quantum particles needed to be taken into account (i.e. rather than interactions between large numbers of particles). The resulting, solvable model sheds new light on the interplay between impurities and their surroundings in 2D semiconductors.

The new approach is remarkably effective at relatively high temperatures (e.g. in a semiconductor anything above a few degrees Kelvin) and low doping (where the electrons' thermal wavelength is smaller than their interparticle spacing), leading to a

> It is remarkable how the low temperature physics of a light-matter coupled system can be described by a high temperature theory.
>
> **DR BRENDAN MULKERIN (MONASH)**
>
> *FLEET Research Fellow*



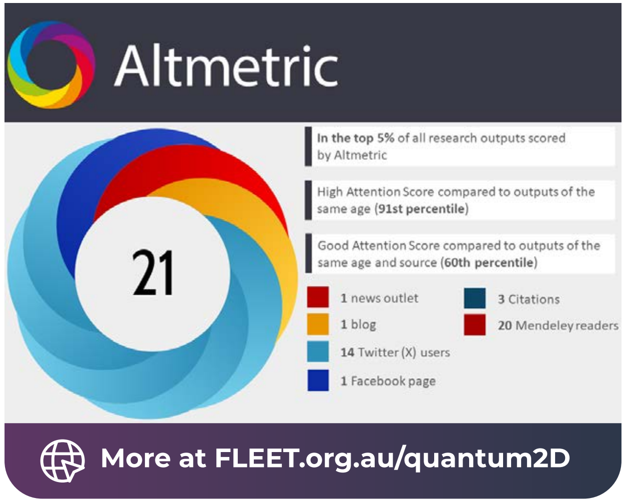
The new technique shows remarkably good agreement with experimental results, essentially perfect at high temperature, with small discrepancies at lower temperatures. Comparison of theoretical (solid dark) and experimental (solid light) photoluminescence spectra at different lattice temperatures.

'perturbatively' exact theory (referring to a quantum system being perturbed from a simple, solvable limit).

"One of the most intriguing aspects of this research is its potential to unify different theoretical models, with the ongoing debate surrounding the appropriate model for explaining the optical response of 2D semiconductors being resolved through the quantum virial expansion," says corresponding author A/Prof Jesper Levinsen (also at Monash).

The quantum virial expansion is expected to have a broad impact, extending its applications to various systems beyond 2D semiconductors.

"Understanding quantum impurity physics will continue to reveal insights and unlock novel properties and new possibilities for understanding, harnessing, and controlling quantum interactions," says corresponding author Prof Meera Parish (Monash).



COLLABORATING FLEET PERSONNEL:

Research Fellow Brendan Mulkerin
Monash

Chief Investigator Meera Parish
Monash

Scientific Associate Investigator Jesper Levinsen
Monash

This research relates to FLEET milestones 3.22 and 3.2.4. See page 19 of FLEET's Strategic Plan at FLEET.org.au/strategic-plan

The study was published in *Physical Review Letters* in September 2023.

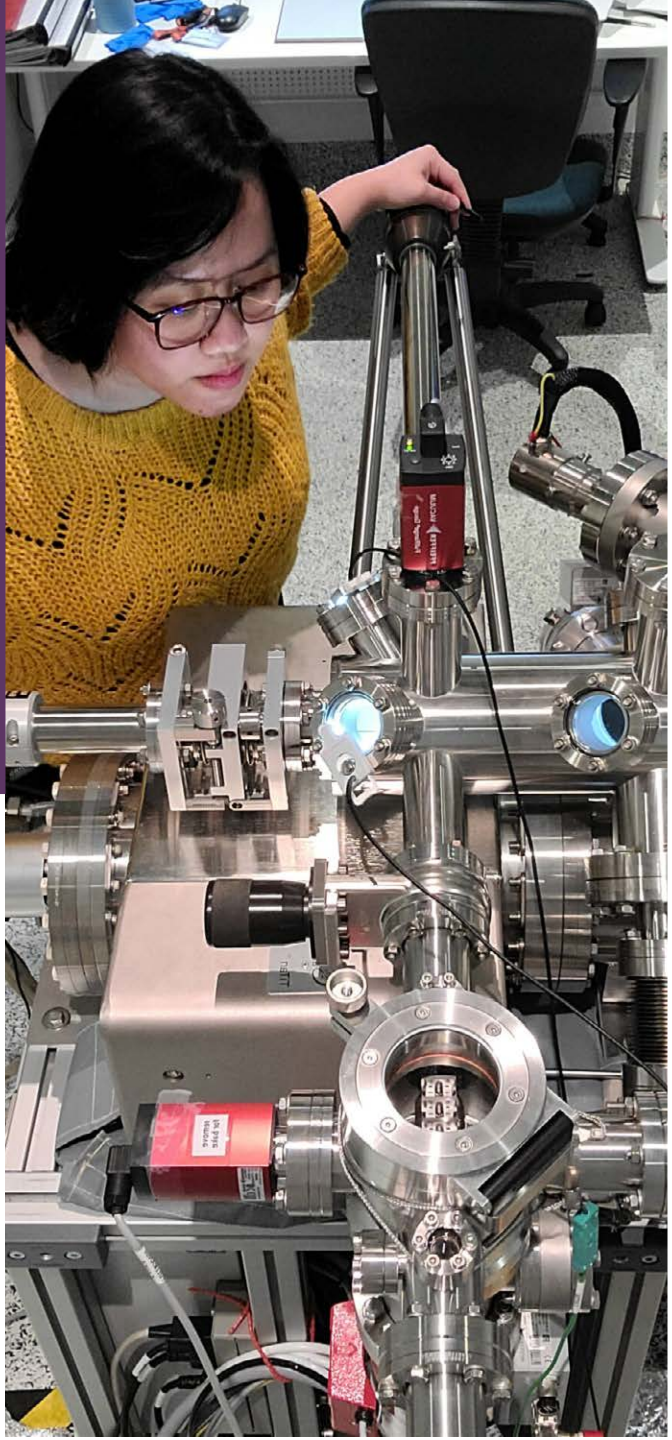
PROF XIAOLIN WANG

Leader, Enabling technology A, UOW

Expertise: design/fabrication and electronic/spintronic/superconducting properties of novel electronic or spintronic systems such as topological insulators, highly spin-polarised materials, superconductors, multiferroic materials, single crystals, thin films, nanosize particles/ribbons/rings/wires

Research outputs (Xiaolin Wang):
609 papers
19,180+ citations
h-index 69 (Scopus)

> ***"Novel materials are fascinating for both fundamental physics and their great practical applications in electronics.***



ENABLING TECHNOLOGY A

ATOMICALLY-THIN MATERIALS

Each of FLEET's three research themes is significantly enabled by the science of novel, atomically-thin, two-dimensional (2D) materials.

These are materials that can be as thin as just one single layer of atoms, with resulting unusual and useful electronic properties.

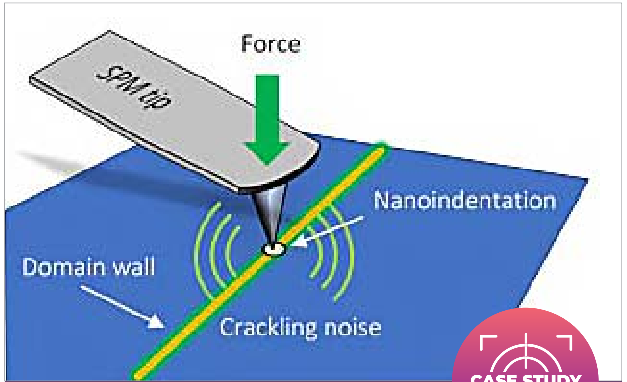
To provide these materials, from bulk crystals to thin films to atomically-thin layers, FLEET has drawn on extensive expertise in materials synthesis in Australia and internationally.

The most well-known atomically-thin material is graphene, a 2D sheet of carbon atoms that is an extraordinarily-good electrical conductor.

FLEET scientists use other atomically-thin materials in their search for materials possessing the necessary properties for topological and exciton-superfluid states.

2023 HIGHLIGHTS

- Characterising ferroelectric domain-wall discontinuities by listening to nanoscale atomic avalanches (see case study p62)
- Enhancing room-temperature ferromagnetism in highly-strained 2D semiconductor $Cr_2Ge_2Te_6$
- Initiating an antiferromagnetic topological insulating state in Tb-doped $Bi_{1.08}Sb_{0.9}Te_2S$ crystals
- Reviewing the role that interactions between heat, charge and spin play in thermoelectricity for more efficient future energy-harvesting applications
- Investigating the superconducting diode effect
- Applying instant-in-air liquid-metal printing technique to derive advanced, stable 2D flexible nanogenerators and ferroelectrics.



CASE STUDY

CHARACTERISING FERROELECTRIC DOMAIN-WALL DISCONTINUITIES BY LISTENING TO NANOSCALE ATOMIC AVALANCHES

READ OUR CASE STUDY

DEFINITIONS

ferroelectricty An electronic analogy to permanent magnetism

ferromagnetic material Material that can be magnetised

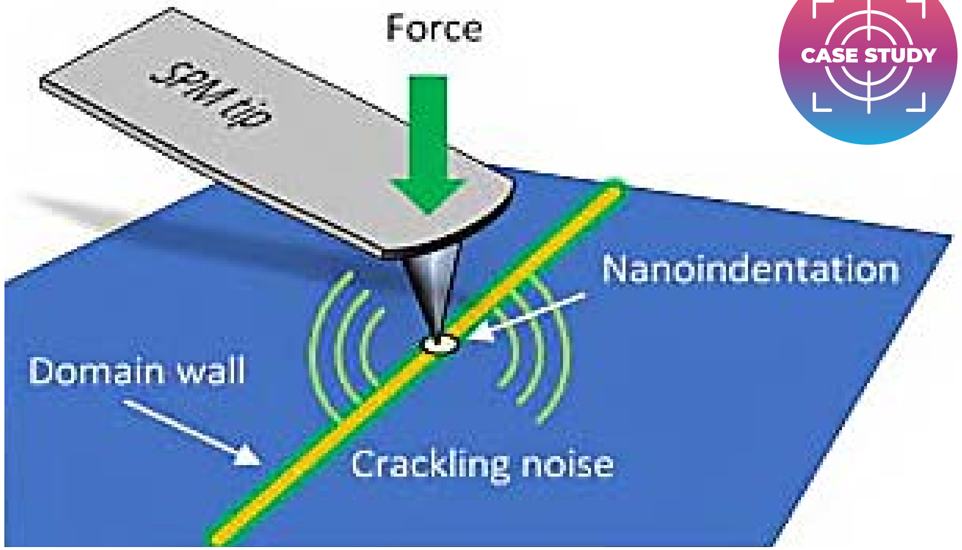
thermoelectricity Conversion of heat into electrical energy

van der Waals (vdW) material A material naturally made of 2D layers, held together by weak van der Waals forces

FLEET.org.au/glossary

Characterising ferroelectric domain-wall discontinuities by listening to nanoscale atomic avalanches

Listening to 'crackling' noise of atoms shifting at nanoscale when materials are deformed towards proposed, future domain-wall electronics



Above: Crackling noise microscopy detects nanoscale avalanches in materials using a scanning probe microscope (SPM) tip.

> Domain walls are highly attractive as building blocks for post-Moore's law electronics.
>
> **PROF JAN SEIDEL (UNSW)**
>
> *FLEET Chief Investigator*

A 2023 UNSW-led FLEET study published in Nature Communications presents an exciting new way to listen to avalanches of atoms in crystals.

The nanoscale movement of atoms when materials deform leads to sound emission. This so-called crackling noise is a scale-invariant phenomenon found in various material systems as a response to external stimuli such as force or external fields.

Jerky material movements in the form of avalanches can span many orders of magnitude in size and follow universal scaling rules described by power laws. The concept was originally studied as Barkhausen noise in magnetic materials and now is used in diverse fields from earthquake research and building materials monitoring to fundamental research involving phase transitions and neural networks.

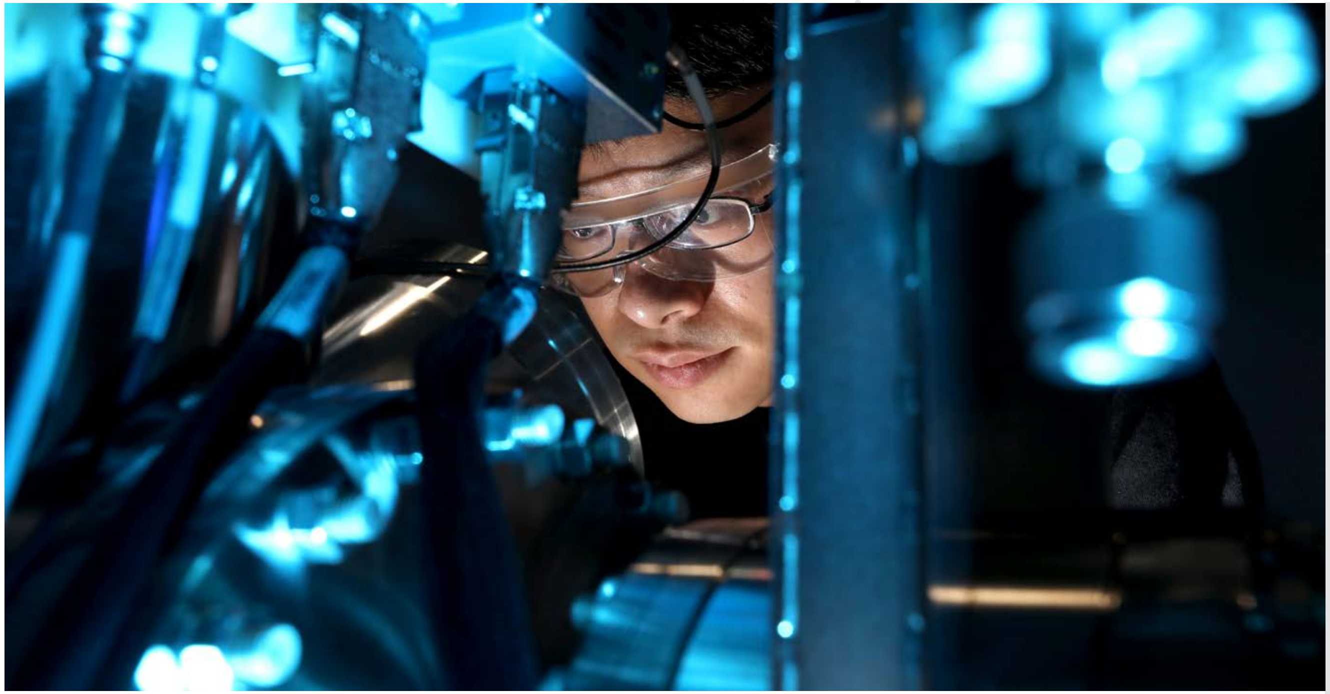
The new method for measuring nanoscale crackling noise developed by UNSW and University of Cambridge researchers is based on scanning probe microscope (SPM) nanoindentation (see figure).

"Our method allows us to study the crackling noise of individual nanoscale features in materials, such as domain walls in ferroelectrics," says lead author Dr Cam Phu Nguyen. "The types of atom avalanches differ around these structures when the material deforms."

One of the method's most intriguing aspects is the fact that individual nanoscale features can be identified by imaging the material surface before indenting it. This differentiation enables new studies that were not possible previously.

In a first application of the new technology, the UNSW researchers have used the method to investigate discontinuities in ordered materials, called domain walls.

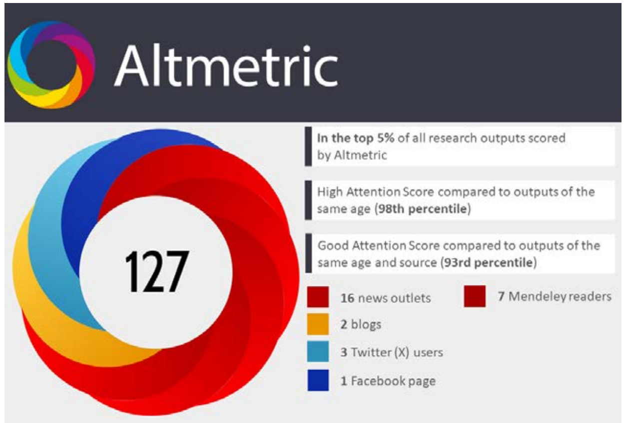
"Domain walls have been the focus of our research for some time. They are highly attractive as building



blocks for post-Moore's Law electronics," says author Prof Jan Seidel, also at UNSW. "We show that critical exponents for avalanches are altered at these nanoscale features, leading to a suppression of mixed-criticality, which is otherwise present in domains."

From the perspective of applications and novel material functionalities, crackling noise microscopy presents a new opportunity for generating advanced knowledge about such features at the nanoscale. The study discusses experimental aspects of the method and provides a perspective on future research directions and applications.

The presented concept opens the possibility of investigating the crackling of individual nanoscale features in a wide range of other material systems.



More at FLEET.org.au/nanolisten

COLLABORATING FLEET PERSONNEL:

PhD student Cam Phu Thi Nguyen
UNSW

Research Fellow Peggy Schoenherr
UNSW

Chief Investigator Jan Seidel
UNSW

This research relates to FLEET milestone M1.11a. See page 19 of FLEET's Strategic Plan at FLEET.org.au/strategic-plan

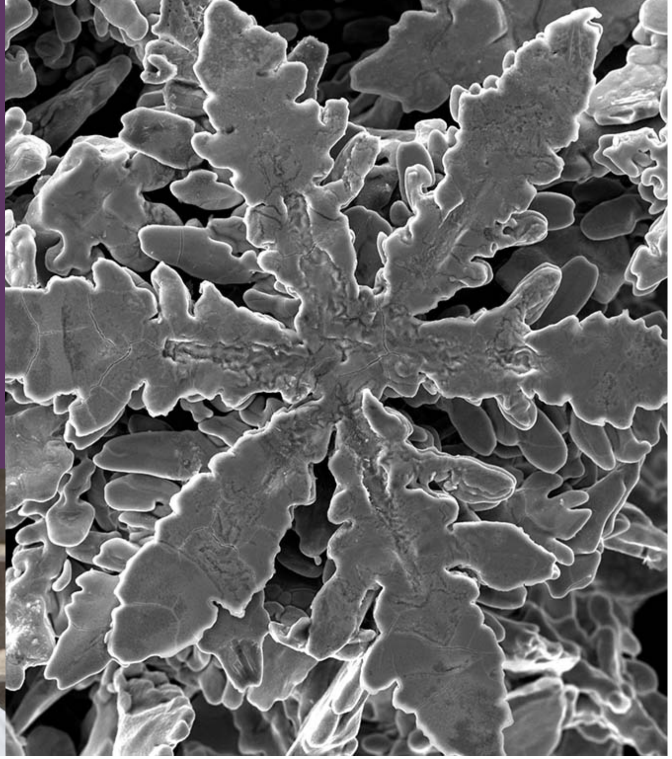
The study was published in *Nature Communications* in August 2023.

A/PROF LAN WANG

Leader, Enabling technology B, RMIT

Expertise: low-temperature and high-magnetic field electron and spin transport; topological insulators; magnetic materials; spintronic and magneto-electronic devices; device fabrication; growth of single crystals, thin films and nanostructures

Research outputs (Lan Wang):
100+ papers
4140+ citations
h-index 35 (Scopus)

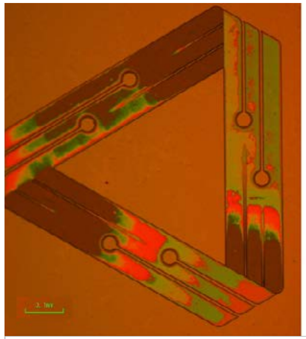


A/PROF OLEH KLOCHAN

Leader, Enabling technology B, UNSW

Expertise: semiconductor physics, nanofabrication, low temperature transport measurements, semiconductor nanostructures

Research outputs (Oleh Klochan):
61 papers
900+ citations
h-index 21 (Scopus)



COMBINING IRRADIATION AND LITHOGRAPHY TO ENGINEER ADVANCED CONDUCTIVE MATERIALS

READ OUR CASE STUDY

ENABLING TECHNOLOGY A

NANODEVICE FABRICATION

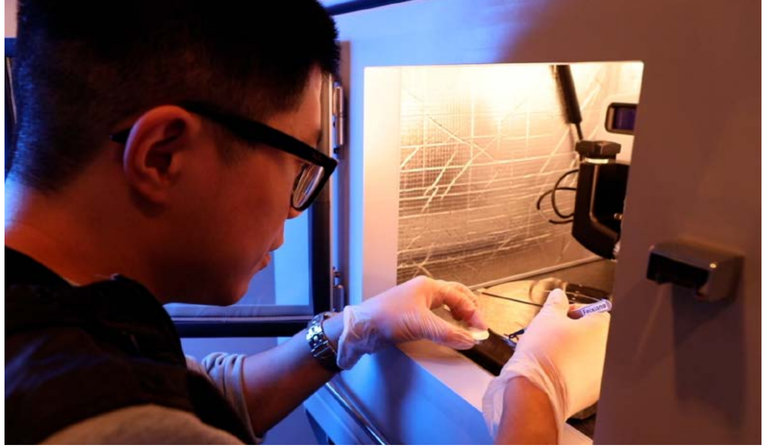
FLEET's research sits at the very boundary of what is possible in condensed-matter physics. Thus, nanoscale fabrication of functioning devices have been key to the Centre's ultimate success.

Specialised techniques are needed to integrate novel atomically-thin, two-dimensional (2D) materials into high-quality, high-performance nanodevices.

For example, successful development of functional topological transistors will require atomically-thin topological insulators to be integrated with electrical gates. And exciton-polariton condensate devices will require atomically-thin semiconductors to be integrated with optical cavities.

Nanodevice fabrication and characterisation link many of FLEET's groups and nodes. Some groups bring expertise in device fabrication, while other groups are stronger in device characterisation.

FLEET brings Australian strength in microfabrication and nanofabrication together with world-leading expertise in van der Waals (vdW) hetero-structure fabrication to build the capacity for advanced atomically-thin device fabrication.



Nanodevice fabrication expertise at UNSW

2023 HIGHLIGHTS

- Combining irradiation and lithography to engineer advanced conductive materials (see case study p66)
- Developing universal electrode pick-up technology for 2D monolayer semiconductors
- Shielding 2D materials: suppressing interfacial phonon scattering in graphene by adding vibrations
- Scalably integrating perovskite in a microcavity
- Transferring large-area topological insulator Bi_2Te_3 films to magnetic and non-magnetic substrate
- Fabricating devices from single crystals of $TbMn_6Sn_6$ (a kagome magnetic material) using focused ion beam
- Creating a new type of topological defect, the 'bubble domain', which possesses giant susceptibilities
- Developing a process for fabrication of patterned graphite gate for 2D materials
- Fabricating magneto-hydrodynamic devices in GaAs/AlGaAs hetero-structures
- Synthesising 2D kagome metal-organic-framework material on atomically-thin hBN

DEFINITIONS

hetero-structure A structure in which two (or more) dissimilar materials are brought together at a controlled interface

irradiation A process for semiconductor device fabrication, using a focussed ion beam to alter a material's conductive properties

kagome metal 2D material with a basketlike lattice structure

lithography A microfabrication technique used to pattern material surfaces or thin films

topological surface edge states Surface states that can carry dissipationless current

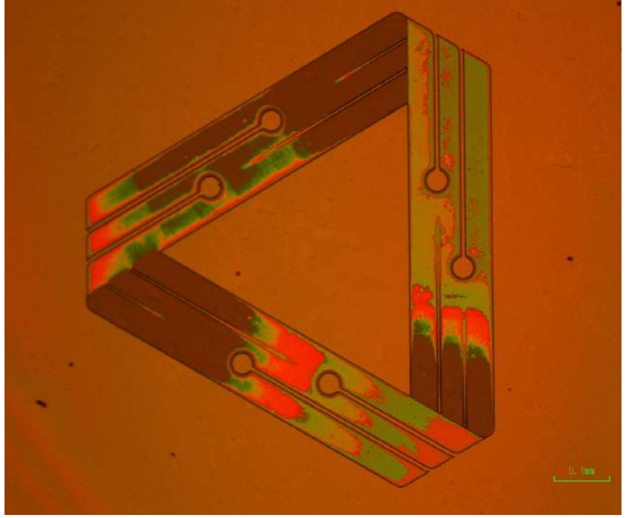
van der Waals (vdW) material A material naturally made of 2D layers, held together by weak vdW forces

vdW hetero-structure A structure made by stacking layers of different vdW materials

FLEET.org.au/glossary

Combining irradiation and lithography to engineer advanced conductive materials

CASE STUDY



Top-down patterning of topological surface and edge states using a focused ion beam for energy-efficient quantum electronics

A new process developed to engineer nanoscale arrays of conducting channels for advanced scalable electronic circuitry unveils a useful pathway towards scalable topological electronics.

Using ion implantation and lithography, investigators created patterns of topological surface edge states on a topological material that made the surface edges conductive while the bulk layer beneath remained an insulator.

Low-energy ion implantation, neutron and X-ray reflectometry techniques at ANSTO supported the investigation, which was led by FLEET researchers at the University of Wollongong.

Investigators created patterns of topological surface edge states on antimony telluride (Sb^2Te_3), producing a 3D topological insulator with gapless, conductive surface edges and energy-gapped insulating bulk interior.

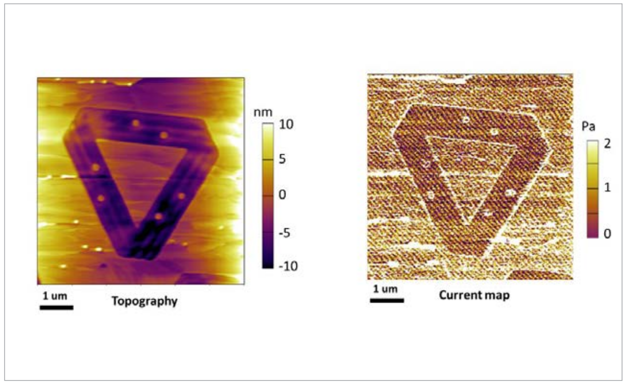
"The irradiation displaced atoms causing the transformation of the surface from a crystalline to a disordered glassy state," explained FLEET Associate Investigator Dr David Cortie (ANSTO), who supervised lead author Abdulhakim Bake.

Ion beam implantation, commonly used to modify the properties of electronic materials by customised doping, has only recently been demonstrated on 2D materials or topological insulators.

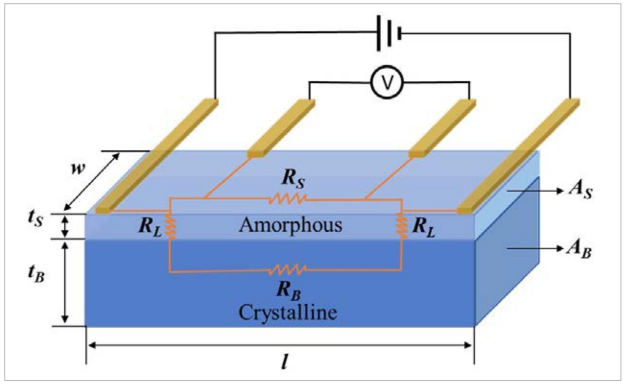
In the work by Cortie's team, lateral patterns were etched on thin flakes of the materials using a focused ion beam (FIB) instrument using low-energy gallium ions, such that the ions penetrate only a few nanometres into the material.

The researchers were able to combine ion beams and lithography to achieve dimensions smaller than 20 nanometres, with the shallow ion irradiation changing the surface's atomic structure and electronic properties.

Importantly, the change in surface conductivity occurred at room temperature, suggesting a radical change in the electronic structure, confirmed by atomic force microscopy measurements by Dr Peggy Zhang, a Women in FLEET Fellow at UNSW.



Using varying angles of the FLEET logo to demonstrate that edge effect on conductivity (with current mapped on RHS) is independent of scan direction with respect to edge orientation



Four-probe contact measurement and corresponding lumped element model of a Ga-FIB device with an amorphous surface layer, with parallel bulk conducting channel

X-ray diffraction and cross-sectional transmission electron microscopy confirmed the phase transition, and further experimentation with X-ray reflectometry and neutron reflectometry provided insights into the optimum ion beam dose to achieve the conversion.

Neutron reflectometry verified the thickness and morphology of the thin films and confirmed that the material remained the same chemical compound after the irradiation.

"The trick here is the judicious choice of the irradiation dose: if you under-irradiate, very little happens to the structure. But if you over-irradiate, you destroy the material via sputtering. We confirmed that we found the sweet spot for amorphisation," said Dr Cortie.

Several different types of material were irradiated, including antimony telluride, bismuth telluride and bismuth selenide.

"In addition to standard FIB techniques, we also took advantage of the low energy implanter at ANSTO which is very flexible and can produce many different types of ions, including the noble gases and transition metal ions," said Dr Cortie.

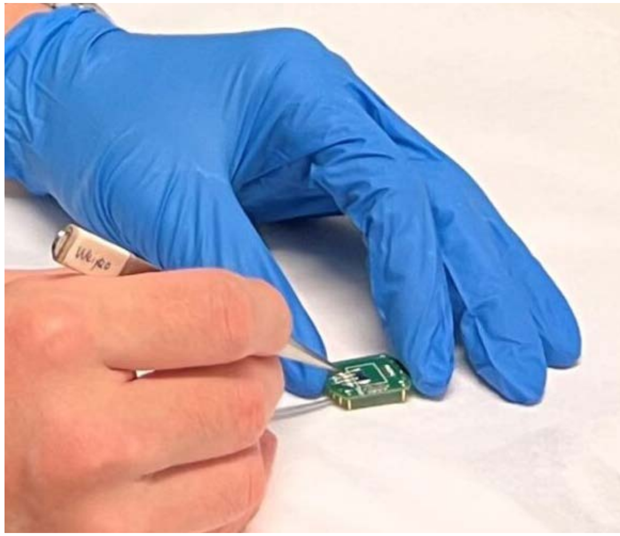
"The fields of amorphous and quasi-crystalline topological insulators are attracting a great deal of attention within the materials science sector. Our work provides some of the first experiments and should be useful to many people working in this field."

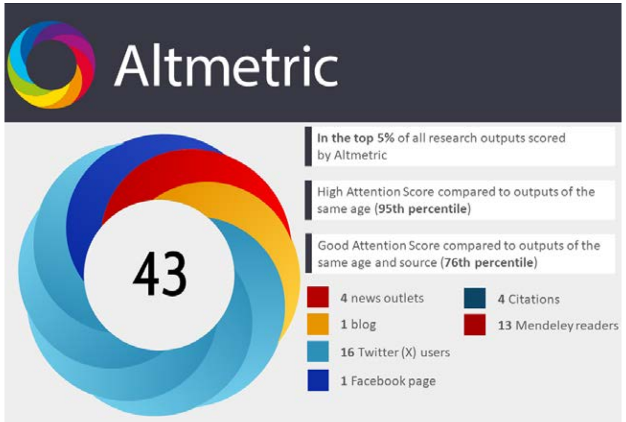
"On the technological front, I also believe we have unveiled a very useful pathway towards scalable topological electronics using ion beams to define surface electronics."

Story first published: **ANSTO**

This research relates to FLEET milestones M1.8 and M1.16. See pages 13 and 15 of FLEET's Strategic Plan FLEET.org.au/strategic-plan

The study was published in *Nature Communications* in March 2023.





More at FLEET.org.au/nanoengineer

COLLABORATING FLEET PERSONNEL:

Research Fellow Abdulhakim Bake *UoW*

Scientific Associate Investigator Peggy Qi Zhang *UNSW*

Research Fellow Grace Causer *Monash*

Research Fellow Weiyao Zhao *Monash*

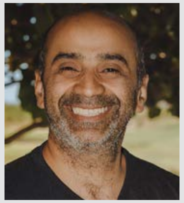
Scientific Associate Investigator Zenjgi Yue *UoW*

PhD student Alex Nguyen *Monash*

Scientific Associate Investigator Golrokh Akhgar *Monash*

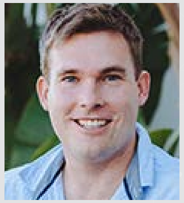
Chief Investigator Julie Karel *Monash*

Chief Investigator Jared Cole *RMIT*



Chief Investigator Nagarajan Valanoor *UNSW*

Chief Investigator Xiaolin Wang *UoW*



Scientific Associate Investigator David Cortie *ANSTO/UoW*

FLEET has built and utilises a network of leading national and international experts to fulfil the Centre's mission.

FLEET'S AREAS OF IMPACT: (See p15)

CAPACITY

INNOVATION

STEM-ED

→ **KEY DATA**

→ **RESEARCH COLLABORATIONS**

→ **PROFESSIONAL COLLABORATIONS**

COLLABORATE

KEY DATA

27
RESEARCH SEMINARS & CONFERENCES ORGANISED

12
NEW RESEARCH COLLABORATING ORGANISATIONS ESTABLISHED

10
FLEET MEMBERS VISITING PARTNER ORGANISATIONS

25
END-USER RELATIONSHIPS ESTABLISHED

28
NEW ORGANISATION LINKS FOR TRAINING & OUTREACH ESTABLISHED

Research Collaborations

Australian Government Australian Research Council
MONASH University
UNSW Sydney
RMIT University
Swinburne University of Technology
Australian National University
University of Wollongong Australia
The University of Queensland Australia

FLEET links over 200 researchers across participating nodes with 22 national and international partner organisations, and has built links with an even wider scientific network.

As evidence of the growing collaborations within the Centre, a sixth of publications in 2023 represented cross-node collaborations – a proportion that has doubled since FLEET's first two years.

FLEET's extensive network of 22 leading national and international research partners is key to fulfilling the Centre's mission.

Out of 94 publications in 2023:

- 15% involved multiple FLEET nodes
- 17% have multiple chief investigators
- 21% were co-published with FLEET partner organisations
- 48% were co-published with scientific associate investigators
- 67% involved multiple chief, associate or partner investigators and/or nodes.

> I think the thing I valued the most at FLEET was being embedded in a broad network of professionals which were more interested in collaborating and building on each other's knowledge rather than in competing with each other.
>
> **DR IOLANDA BERNADO**
> *(IMDEA Nanociencia, Spain)*
> *FLEET alum*

It speaks to the strong community within the Centre that, despite this being the last full year of FLEET's operation, an end-2023 equity and diversity survey found that 55% of respondents see themselves continue collaborating with FLEET members in the next three years or more. (See survey p20.)

JUMP-STARTING THE AUSTRALIAN ELECTRONIC MATERIALS COMMUNITY: FEMRA

FLEET's activity and success over five years has galvanised the Australian electronic materials research community and added momentum to a rising semiconductor community.

The health of the greater scientific community opens up new opportunities for further scientific advancement of FLEET's discoveries, commercial development of intellectual property created to date, and new research programs stemming from capacity and relationships built up through FLEET's funding period.

In 2023, FLEET hosted the Future Electronic Materials Research in Australia workshop (FEMRA), looking at pathways for Australia's research community to build capacity, networks and funding support addressing 'grand challenges' in electronics materials.

US-AUS TRANSPACIFIC AND EU-AUS COLLOQUIA

FLEET's transpacific colloquium series continues to maintain links between physics communities in Australia and North America. In 2023 the series has been expanded to include Europe-based speakers.

Since its initiation, the series has hosted 35 colloquia with speakers alternating between North American, Australian and now European-based researchers. Gender mix has been an ongoing focus for organisers, and in 2022–23 over half of our speakers have been women.

In 2023 the Centre hosted seven colloquia covering topics from polariton lasers and non-Hermitian topology to light–matter interactions and nanophotonics. Cumulatively, 283 people attended these seminars in 2023, including 26 non-FLEET members.

The series' organisation committee is led by FLEET Associate Investigators Dr Dmitry Efimkin (Monash),

FLEET legacy will be:

- Stronger, lasting links between Australian and international science communities
- Ongoing benefit to Australia from established FLEET networks and linkages.

Prof Susan Coppersmith (UNSW) and Prof Victor Galitski (University of Maryland), who direct series strategy, coordinate publicity and manage speaker recruitment, seeking expertise specific to FLEET goals and research interests.

FLEET, with Centre partners Joint Quantum Institute (University of Maryland) and Monash University, inaugurated the transpacific colloquium series in 2020, presenting novel developments in condensed-matter and cold-atom physics.

FLEET.org.au/transpacific

Professional collaborations

FLEET continues to proactively seek out opportunities to partner with other science and educational organisations to further the reach of Centre-relevant science, advance equity issues and develop future leaders.

For example, in 2023 the Centre:

- Delivered the fifth year of FLEET's Future Electronics unit with John Monash Science School (JMSS)
- Worked with JMSS and Monash Faculty of Science to arrange hosting of four work-experience secondary students
- Conducted interactive workshops for three JMSS programs: Immersion Day, Regional Exchange and MySci
- Sponsored, and was a member of the steering committee to deliver the 2023 National Science Quiz. Partners/sponsors were the following: ARC Centres of Excellence for Plant Success (convenors), Engineered Quantum Systems (EQUS), Synthetic Biology (CoESB), Gravitational Wave Discovery (OzGrav), Climate Extremes, Exciton Science, Plants for Space, and MATRIX, Australian Data Science Network, Optima, CSIRO, Melbourne Centre for Data Science and RMIT University.
- Co-founded the multi–Centre of Excellence mentoring program (see p98)
- Delivered nine joint FLEET seminars, with the Australian Institute of Physics (AIP), Monash School of Physics and Astronomy (two seminars), ARC Centres of Excellence CoESB and EQUS (two seminars), and UNSW School of Physics (three seminars)
- Co-organised the inSTEM equity development workshop with nine other ARC Centres of Excellence: EQUS, TMOS, All Sky Astrophysics in 3 Dimensions, Australian Biodiversity and Heritage, Quantum Computation and Communication Technology, Peptides and Protein Science, Dark Matter Particle Physics, Exciton Science and OzGrav
- Continued to strengthen the global condensed-matter community via the US-Aust transpacfic and EU-Aust series of talks, with the Joint Quantum Institute and Monash School of Physics and Astronomy
- Gathered 80 researchers to discuss the future of electronic materials research in Australia (FEMRA 2023)
- Continued the traditional Gordon Godfrey workshop with the UNSW School of Physics
- Sponsored FLEET-Europe workshop on transport in exciton condensates and exciton insulators with partner organisation University of Camerino.

In early 2024, FLEET will deliver the 'Better Futures Innovation Challenge ' hackathon along with four other ARC Centres of Excellence: EQUS, Exciton Science, OzGrav and TMOS (see p27).

Wide-ranging collaboration across research, equity and outreach

CASE STUDY

FLEET and MacDiarmid Institute members teaming up to conduct science outreach workshops, and share learnings between the two centres

In 2023 FLEET's five year partnership with NZ's MacDiarmid Institute saw collaboration extend to a successful science outreach program and ongoing discussions about diversity in science.

FLEET's partnership with NZ materials science institute the MacDiarmid Institute has proven to be highly fruitful, establishing excellent research alliances. Since the initiation of the partnership in 2019, members have jointly produced six impactful research papers. In addition to the successful research partnership, the collaboration has also extended into broader domains such as equity, training and science outreach.

At the 2023 Advanced Materials and Nanotechnology (AMN10) in Rotorua, NZ, this wider partnership was put to work: FLEET researchers joined the MacDiarmid Institute outreach coordinator and institute members in a significant program of schools outreach in and around Rotorua, visiting over 300 students and teachers at seven schools.

The program reached schools that had rarely if ever hosted visiting scientists and schools with a high proportion of indigenous (Maori) students and teaching frameworks.

Most schools had a student population with more than 50% Maori, with language, culture and traditional science (matauranga Maori) integrated into the curriculum.

This was an opportunity for FLEET communications and outreach facilitators, as well as participating members, to learn from another international research centre on outreach to indigenous and rural communities.

Over four days, 25 volunteers from FLEET and the MacDiarmid Institute visited seven schools and presented a variety of hands-on science workshops to students ranging from year 4 to 9, in a program coordinated with Tuhura Otago Museum that resulted in learning for the participating scientists and professionals as well as the students.

> “I very much appreciated the support and willingness of FLEET and MacDiarmid Institute volunteers who helped us take nano and quantum science to seven Rotorua schools. The outreach effort was extremely well received, with universally enthusiastic feedback from the schools.
>
> **PROF PAUL KRUGER (MACDIARMID INSTITUTE)**
>
> *Deputy Director Outreach and Engagement*

"The students were not the only ones learning during our school visits," says FLEET Outreach Coordinator Dr Jason Major. "We were struck by the successful integration of Maori-based knowledge systems and language in the education system, as well as by MacDiarmid's wider efforts in promoting more equitable uptake of STEM in indigenous and Pacific communities."

"This prompted a discussion among FLEET and MacDiarmid colleagues about what we could learn from the Kiwis to improve integration of Australia's indigenous culture and science into how we conduct outreach and public engagement in Australia," says Jason.

Discussions between MacDiarmid Institute indigenous and schools engagements experts have continued in an effort to translate some of the NZ learnings about STEM equity and engagement in the Australian science community.

"We can, and plan to, learn a lot more from our MacDiarmid colleagues," says FLEET Communication Coordinator Errol Hunt. "And to do what we can to ensure the sharing of learnings continues past the tenure of the formal FLEET–MacDiarmid partnership."

> It has been great to see our partnership working on so many levels!
>
> **PROF NICOLA GASTON (MACDIARMID INSTITUTE)**
>
> *Co-Director*

The FLEET volunteer squad taking time out from the conference to assist were: Karen Bayros and Yik Lee (RMIT) and Golrokh Akhgar (Monash).

> Partnering with FLEET for the outreach and engagement around AMN10 provided an opportunity to connect up our resources and ideas and build on our intersecting research areas. By combining our outreach content and delivery teams, we were able to more than double the impact of our outreach. We've connected our Deputy Director Māori A/Prof Pauline Harris with FLEET and others in the engagement sector in Australia and it's been interesting and exciting to continue to meet, speaking further about engagement with indigenous peoples.
>
> **VANESSA YOUNG (MACDIARMID INSTITUTE)**
>
> *Strategic Engagement and Communications Manager*

FLEET.org.au/rotorua2023

ENGAGE WITH FLEET

- → KEY DATA
- → ENGAGING WITH STUDENTS
- → SHARING FLEET RESEARCH
- → FLEET ONLINE

FLEET'S AREAS OF IMPACT: (See p15)

FLEET has an extremely ambitious program of STEM outreach and communication, engaging Australians with science – from school children to the public to policymakers

FLEET ENGAGEMENT

967
FACEBOOK FOLLOWERS
• 41 NEW •

1793
TWITTER FOLLOWERS
• 185 NEW •

1724
LINKEDIN FOLLOWERS
• 220 NEW •

19,600
VIEWS OF FLEET YOUTUBE CHANNEL

BLOGS
42

12,300
AVERAGE MONTHLY UNIQUE PAGE VIEWS

NON PEER REVIEWED ARTICLES
15

PRESS RELEASES
8

MENTIONS IN ONLINE MEDIA
159

PRINT ARTICLES
13

RADIO INTERVIEWS
10

6200
AVERAGE MONTHLY NEW USERS VISIT FLEET.ORG.AU

E-NEWSLETTERS
4

FLEET OUTREACH

Spreading a passion for science: **Outreach**

FLEET shares the responsibility to increase the participation of students in science, and to increase the number of girls and women participating in physics, chemistry and engineering.

FLEET's outreach activities improve public awareness of FLEET research and scientific literacy among school students. FLEET members get a greater appreciation of their audience's interests, understanding and values, and learn how to effectively communicate with them.

FLEET focuses significant efforts on science outreach, with the aim of:

- Increasing the participation of students in science and physics
- Increasing awareness, passion and appreciation for science in the general public
- Improving the outreach skills of FLEET members
- Facilitating public discussion of FLEET-specific research.

Director Michael Fuhrer sharing FLEET research at a Monash Alumni Event

2023 has been an intensive year of outreach with 62 FLEET members involved in 102 outreach activities.

The wide-ranging activities in 2023 include a public lecture on the Nobel Prize in physics, industry and government briefings, hands-on school holiday programs, lab tours, student workshops, participation in 100 Climate Conversations, judging at student STEM fairs, the National Science Quiz, the ongoing JMSS Future Electronics unit, and competing in (and winning) the 3-Minute Thesis.

Karen Livesey (University of Newcastle) starred this year, with more than 30 presentations to students, teachers and the public as part of the AIP Women in Physics tour.

A large proportion of FLEET's 2023 outreach was focused on student workshops.

The Centre has built a series of workshops that, based on continual evaluation and refinement, we have confidence will stimulate students, improve their scientific literacy and critically engage them with the problem of digital technologies' unsustainable energy demands.

2023 HIGHLIGHTS

- Reaching over 11,000 students, teachers and members of the public in 2023
- 63 FLEET members actively involved in Centre outreach
- Successfully showing that primary students can learn quantum physics via FLEET's quantum circuits workshop for primary school students – see p80
- Increasing students' and the public's awareness and critical thought about FLEET's research and how society uses digital technology at the Sydney Science Trail – see case study p82
- Working with NZ's MacDiarmid Institute to introduce 25 practising scientists to 300+ students at seven largely indigenous-majority schools around Rotorua, as part of the AMN10 workshop – see case study p73.
- Improving the visibility of women in science: see p19 regarding FLEET outreach events increasing the public visibility of women in STEM, and thus allowing girls to see a viable path for themselves in science. 2023 saw a female presence in almost 80% of public FLEET outreach events.

IN 2024...

FLEET will continue to visit schools in the first half of 2024, and take advantage of relevant public events where we can enlist the power of the levitating superconductor.

We will also ensure ongoing use and access for the outreach assets that the Centre has created over its seven-year term, including a sustainable host for the JMSS Future Electronics unit, a home/homes for the Mobius superconducting track, ensuring access to online resources/worksheets, etc.

We have continued to experiment with the quantum circuits workshop, developed to introduce primary students to quantum physics. We have now assessed five of these workshops and, while there is still room for refinement, we are now confident that primary students can conceptualise quantum physics. See case study p80.

2023's big public event, the Sydney Science Trail, was a busy, exciting week in front of 1800 teachers, students and members of the public. While FLEET's levitating superconductor was as effective as always, the key role of FLEET's interactive exhibit was to engage students and adults with the problem of digital technology's unsustainable energy consumption. The outcome was some thought-provoking dialogue and a common desire to see a socially-responsible digital future. See case study p82.

FLEET's legacy will be:

- Among school students, improved science literacy and critical thought about FLEET research and society's use of digital technology
- Greater public awareness about FLEET's research and the problem of sustainable computing
- Improved critical thinking about society's use of digital technology.

CASE STUDY

Why teach primary students quantum physics?

Widening the reach of quantum teaching towards a 'quantum savvy' Australia

In 2023 FLEET developed a hands-on workshop to engage primary school students with quantum physics, talking about how electricity and circuits work at the quantum level.

Primary students can learn quantum physics, so why not teach it?

Pre- and post-workshop evaluation activities embedded in the nine quantum circuit workshops we ran this year have helped FLEET understand the impact and effectiveness of the program. They show that primary school students:

- Can successfully conceptualise the quantum model of an atom and understand that electrons have a wave-like behaviour
- Learned that the flow of electrons is necessary to generate electrical energy
- Began to conceptualise the nature of electrical resistance at the quantum level and could link this to FLEET's mission to develop low-energy electronics
- Could think critically about the unsustainable energy consumption of digital technologies.

WHY TEACH QUANTUM TO PRIMARY SCHOOL (OR NON-SCIENCE-FOCUSED SECONDARY SCHOOL) STUDENTS?

Australia's future industries will include a higher proportion of quantum technologies.

FLEET's part towards building the quantum workforce that will support such a future includes an impressive 135 quantum-skilled higher degree by research graduates.

But we believe there is more we can do towards building a quantum-savvy workforce and quantum-savvy community. We believe that process begins well before 'Quantum 101' in a university physics degree.

"There are many 'opportunities' to help teach quantum at primary school level," says FLEET Outreach Coordinator Dr Jason Major, who developed the primary schools program.

"The world we inhabit and interact with exists because of quantum physics. Everything from mobile phones (superposition and band theory) to solar panels (energy quantisation) exist because of our understanding of quantum physics. Even energy from the Sun only occurs because of quantum physics (tunneling)."

"Despite this, there is a disconnect between science taught in schools and science of the modern world. Our primary school curricula lack any topics on quantum concepts."

> There is a disconnect between science taught in schools and science of the modern world. Our primary school curricula lack any topics on quantum concepts.
>
> **DR JASON MAJOR**
>
> *FLEET Senior Outreach Coordinator*

FLEET's quantum circuits workshop, made available to schools via the FLEET Schools web resource, will help primary students build familiarity with quantum concepts and the physical reality of how the world works.

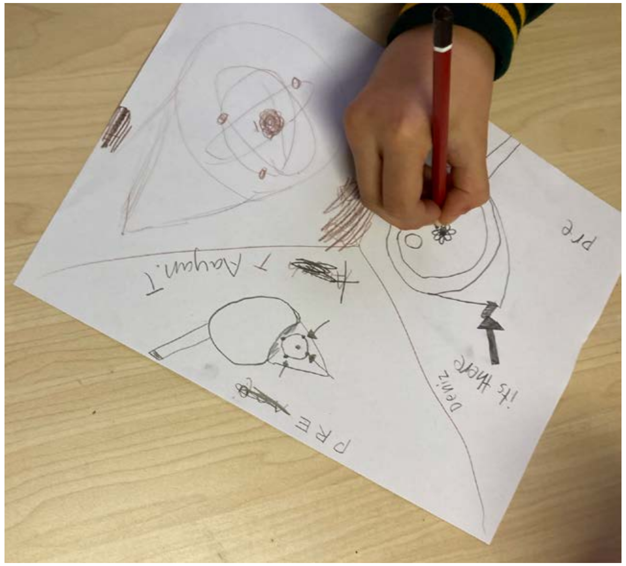
Guided role-play exercises engage students' minds and bodies simultaneously in understanding atomic structure and how electrical resistance works at the quantum level. Students apply this knowledge to a graphite-circuit activity, using heavy pencils to draw circuits using electrically-conductive graphite 'wires' to connect an LED and 9 V battery.

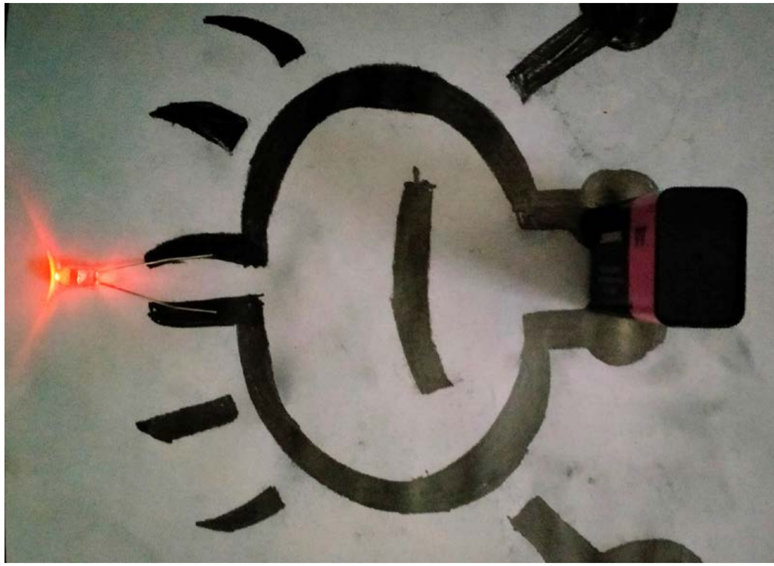
Discussions and activities before and after these exercises support the conclusion that the workshops are effective.

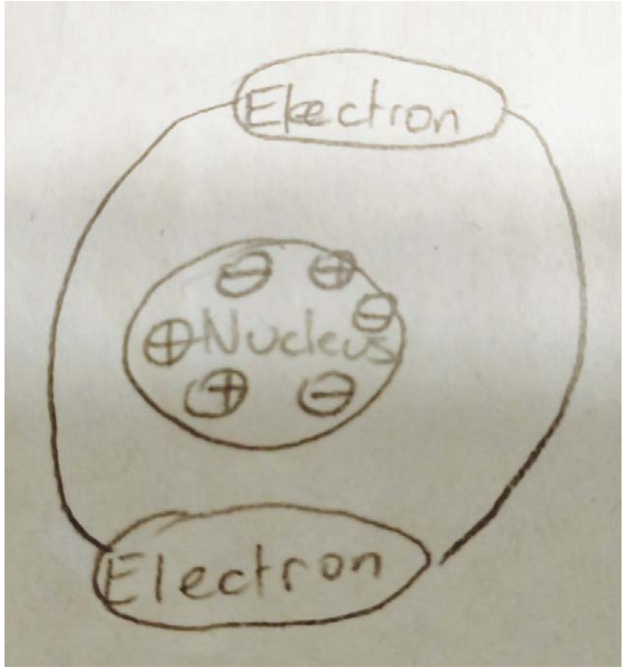
For example, there is a distinct shift in the way students interpret the atom. Drawings of atoms made by students before the workshop show either classic, cartoon Bohr model atoms (electrons in distinct orbits around the nucleus), abstract blobs, or something the resembles a virus. Pre-workshop drawings usually also lack any labelling of protons, neutrons and electrons.

In the post-workshop drawings, students' conceptualisation shifts towards a quantum model, where the position of the electrons around the nucleus resembles a cloud and their precise position is uncertain, or is based on probabilities. Electrons are more often described and, drawn as, waves.

FLEET.org.au/primaryquantum







Hands-on exercises engage students' brains.

CASE STUDY

Levitating superconductor and the desire for a socially-responsible digital future

Sparking new understanding at the Sydney Science Trail

> “To have so many members actively involved in science outreach has been one of FLEET’s significant points of difference, with benefits for our members’ transferable communication skills and confidence, as well as to the diversity of scientists visible to students. The goal of every member delivering 20 hours of outreach each year was always ambitious, but it has driven exceptional outreach results.
>
> **A/PROF AGUSTIN SCHIFFRIN**
> *FLEET Outreach Committee Chair*

With 1800+ students and members of the public coming through the Sydney Science Trail Expo in 2023, FLEET’s stall was well positioned to engage minds with the Centre’s key mission challenge of unsustainable digital energy consumption.

The levitating superconductor may have been the initial attraction, but the main impact of FLEET’s presence at the 2023 Sydney Science Trail was a shift in public awareness and understanding about how society uses digital technology that led to a call for a socially-responsible digital future.

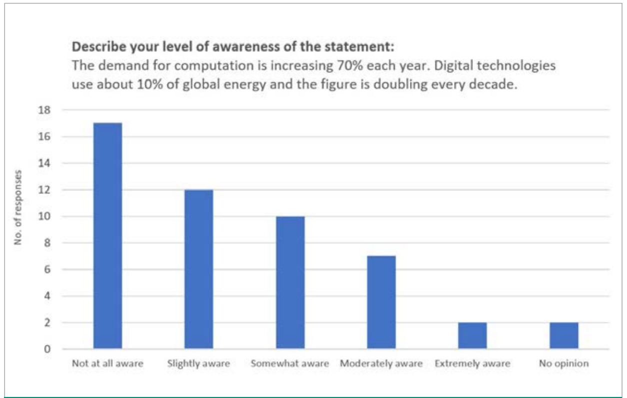
Alongside learning a bit of quantum physics, our key objective at the event was to engage visitors in constructive dialogue about FLEET’s research problem: the increasing and unsustainable energy consumption of digital technologies.

“If we want technologies to be aligned with our stakeholders’ expectations and values, if the public are to have agency and be empowered to make informed decisions about acceptable ways to solve societal problems, then we need to do more than just tell people about the science,” says FLEET Outreach Coordinator Dr Jason Major.

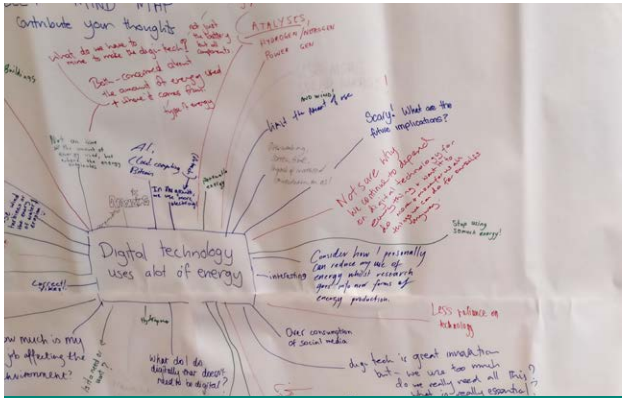
“Public events such as the Sydney Science Trail are a great opportunity to engage people in critical dialogue about our research and research problem, to begin their process of thinking critically about the problem and facilitate their ability to participate in solutions.”

About 1300 members of the public and 560 students and teachers from 35 schools and home-school networks visited the FLEET exhibit held at the Australian Museum, Sydney.

Before visiting the FLEET exhibit, most people had minimal or no awareness of the problem of the energy consumption of digital technology.



A survey conducted before people engaged with FLEET at the Sydney Science Trail show most people had little or no awareness about the high level of energy consumed by digital technology.



"Technology isn't necessary for survival. What do I do digitally that doesn't need to be digital? What do we have to mine to make the digital technologies – not just the battery, but all components. How much is my job affecting the environment?"

Visitors' thoughts and ideas sparked by the prompt 'Digital technology uses lots of energy'.

FLEET's levitating superconductor always draws the crowds, enabling constructive dialogue about FLEET's research and research problem: the increasing and unsustainable energy consumption of digital technology.

FLEET.org.au/sydney2023

Their experience with the FLEET exhibit had a strong impact on their awareness, and indeed understanding, of society's use of digital technology. Visitors to the exhibit began to think critically about the value we place on digital technology.

When prompted to think about the energy consumption of digital technology, visitors' ideas for possible solutions fell into one of two different approaches: a perception that technology will underpin any solution to the problem, or a belief that the problem requires socially-focused or cultural solutions.

The 'tech-fix' approach included developing and implementing low-energy electronics and using a greater proportion of renewable-energy sources. However, there was a strong concern about the source and use of the materials that would enable new low-energy electronic technologies.

Visitors considering a 'cultural' approach called for a shift in how we value digital technology. People began to question their own and society's reliance on digital technology and which digital technologies have a socially-responsible function versus those that are potentially frivolous or unnecessary.

The emphasis for everyone was a recognised necessity to decrease energy usage and promote a transition towards a more socially-responsible digital future.

Coordinated by the Australian Museum, the Sydney Science Trail Expo is a key part of the Museum's mission to inspire curiosity and interest in STEM and showcase the Australian science community's innovations and achievements.

A survey conducted before people engaged with FLEET at the Sydney Science Trail show most people had little or no awareness about the high level of energy consumed by digital technology.

Results from one of the exit survey questions suggests that following their experience with the FLEET exhibit most people had a new perspective about how society uses digital technology.

Sharing FLEET research: communication

Centre communications cover both internal and external needs. While the two audiences are very different, base content is used across both areas to maximise efficiency.

FLEET's communication functions include:

- Internal communications to maintain a cohesive Centre
- Informing the Australian public of the benefits being gained from research funded by the ARC
- Supporting FLEET's outreach functions to build a more science-aware public
- Appropriately communicating FLEET's research outputs to different audiences, from the general public to the research community and potential collaborators, industry partners and end users
- Building the transferable communication skills of FLEET members.

In 2023 FLEET continued its focus on driving self-sufficiency in communications for members. This year FLEET members wrote 15 articles, building important skills for their post-FLEET careers.

The move three years ago to begin publishing members' articles first on the FLEET website has paid off, allowing easy subsequent distribution to other science platforms. Seven science-based articles written by members in 2023 were republished 71 times on scientific platforms.

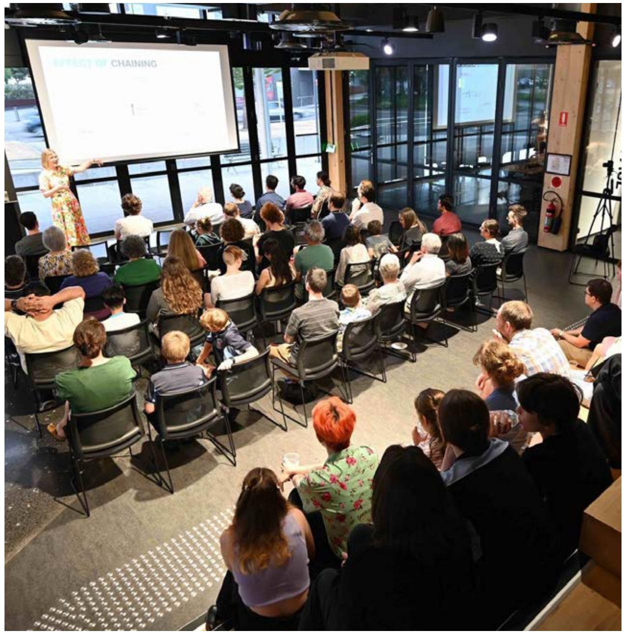
After FLEET funding ends in mid-2024, members will no longer have such easy access to a dedicated communications person. Building members' self-sufficiency in communications will enable continued, wider sharing of their own science.

In addition, FLEET will work with university teams in 2024 to maximise that channel for publishing new science, post-FLEET.

FLEET's increased activity in research translation in 2023 created opportunities for more translation-focused communication, both for the 10 projects selected for FLEET Translation Program funding (supporting project members in writing articles describing possible applications, see p26) and in coaching the 20 poster presenters at the industry–academia Meet FLEET event (see p28).

2023 HIGHLIGHTS

- Supporting industry-translation efforts in FLEET Translation Program and Meet FLEET – see p26
- FLEET members taking control of their own communications and writing 15 non-peer reviewed articles in 2023
- Continued training in 'DIY' communications for early-career researchers (ECRs)
- 8 radio interviews by Karen Livesey as part of her AIP women in Physics tour
- Two all-Centre meetings: the FLEET annual workshop in Lorne and a legacy workshop at Surfers Paradise (see images p86-89).



INTERNAL COMMUNICATION

FLEET's internal communications function to:

- Foster Centre cohesiveness, both between participating nodes and between different research areas
- Improve understanding (e.g. between two quite diverse research fields: quantum information theory and nanodevice fabrication)
- Encourage collaborations between nodes and across research areas
- Ensure members know they are supported by the Centre
- Disseminate important information to members in a timely fashion
- Support other Centre strategic priorities (e.g. in training, outreach and equity).

FLEET's legacy will be:

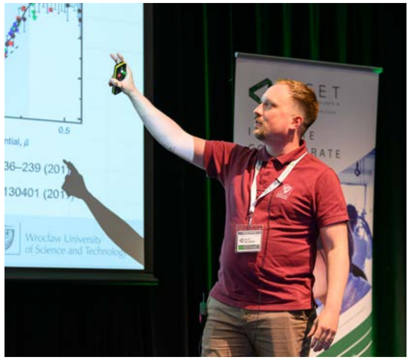
- Improved public science literacy
- Improved public understanding of quantum science, electronics and sustainable computing
- Strong, lasting links between Australian and international science communities
- Better communication skills amongst Australia's next generation of science leaders
- Improved public perception of diversity in science.

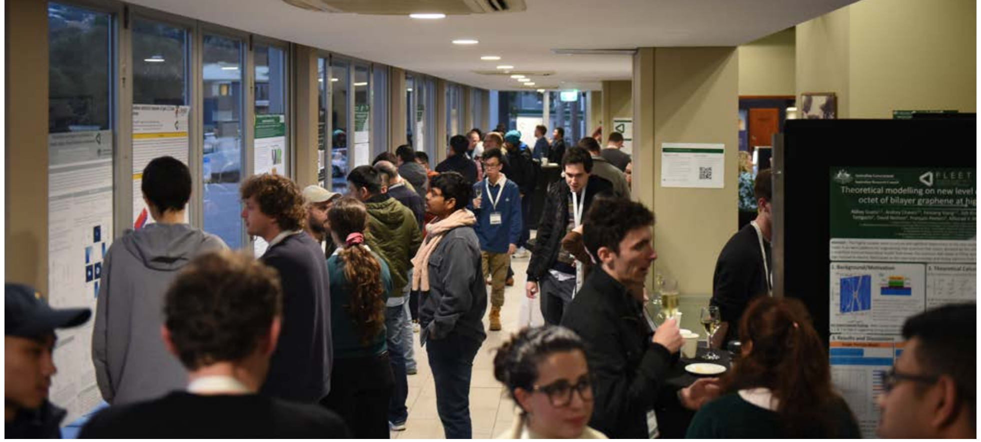
LORNE 2023

Two major FLEET gatherings in 2023 brought the Centre's 200-odd members together to share research and other achievements.

The Centre's last annual workshop in Lorne Victoria featured just under 120 members, family and affiliates, 35 scientific talks (over 60% of them by ECRs), 30 accompanying family (17 kids), a cultural celebration dinner, karaoke, quiz, lawn bowls, and lots of unstructured time for collaborative discussions.

More at FLEET.org.au/Lorne2023






FAITH NO MORE

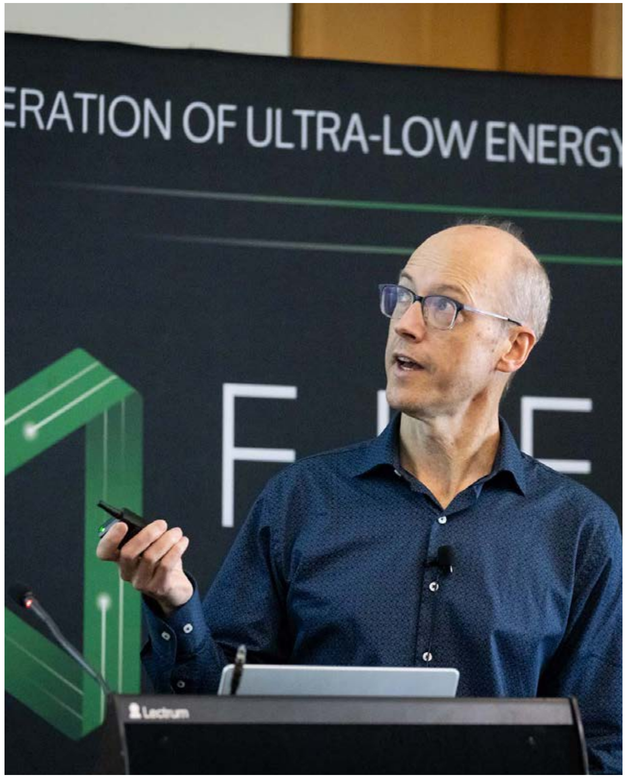

Some keywords that reflect what FLEET means to you
food

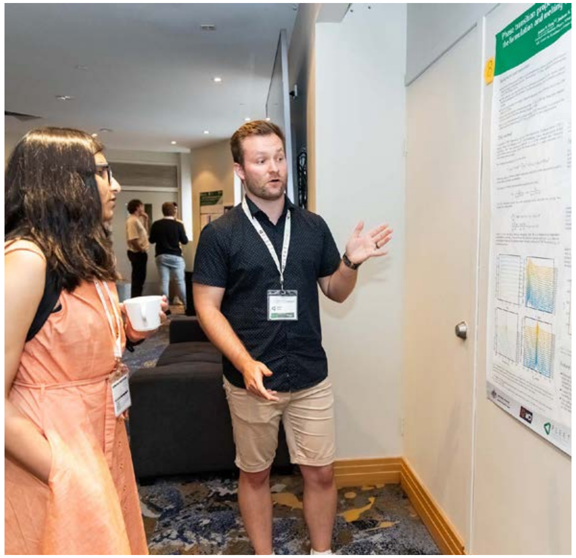
FLEET's Legacy Meeting in Surfer's Paradise, Queensland, celebrated seven years of transformative innovation, capacity building and the development of future STEM leaders, with presentations covering Centre highlights in research, equity, outreach, training and translation.

SURFERS PARADISE 2023

More at FLEET.org.au/Surfers2023


FUTURE
LOW-
ENERGY
ELECTRONICS
TECHNOLOGIES


ERATION OF ULTRA-LOW ENERGY



FLEET ONLINE

242,300 TWEET IMPRESSIONS

425 MENTIONS

45,500 PROFILE VISITS

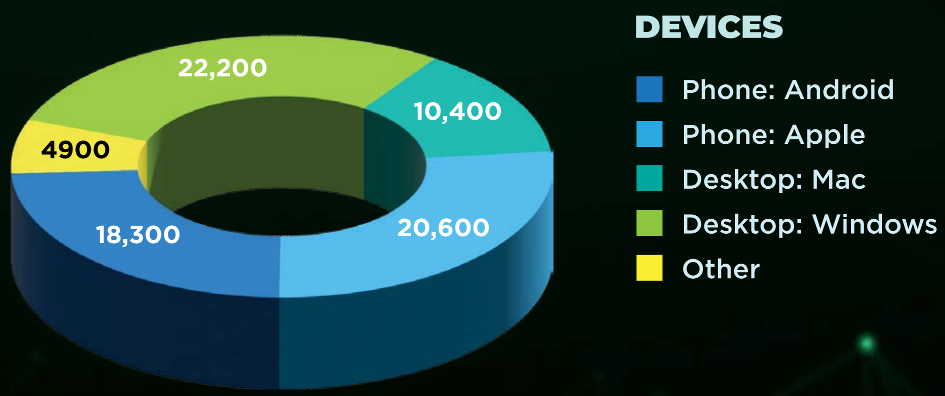
1793 TWITTER FOLLOWERS

5910 PEOPLE REACHED 28-DAY AVG.

1065 FOLLOWERS FLEET FACEBOOK PAGE

25,501 PEOPLE WHO SAW OUR POSTS

1007 PEOPLE WHO ENGAGED WITH OUR POSTS



FLEET ONLINE

FLEET.org.au

1.57 PAGES PER SESSION

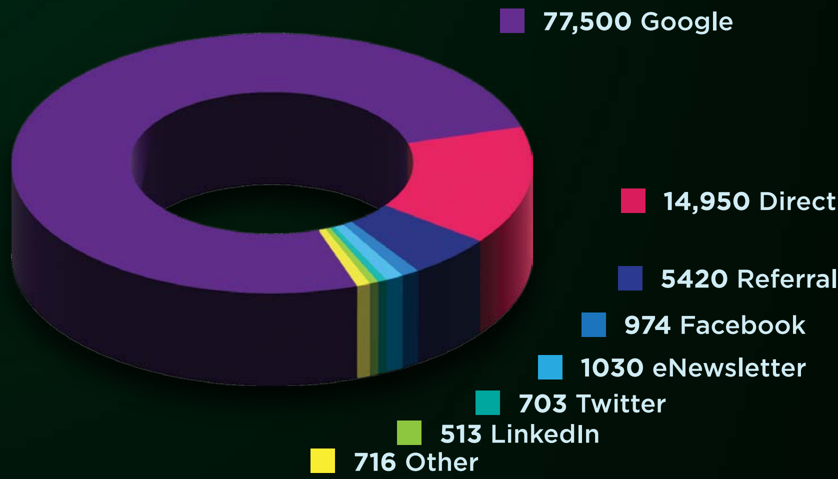
101,300 SESSIONS

159,400 UNIQUE PAGE VIEWS

42 BLOG POSTS

74,400 NEW USERS

TRAFFIC SOURCE



1632 PAGE VISITS

1757 FOLLOWERS

70,309 POST VIEWS

Developing future
Australian science leaders

FLEET'S AREAS OF IMPACT: (See p15)

CAPACITY

INNOVATION

EDUCATION & TRAINING

EDUCATION & TRAINING COMMITMENTS

7
RESEARCH WORKSHOPS & CONFERENCES ORGANISED

1563
CUMULATIVE NUMBER OF CENTRE MEMBERS ATTENDING TRAINING WORKSHOPS

11
RESEARCH AND PROFESSIONAL DEVELOPMENT WORKSHOPS

498
CUMULATIVE NUMBER OF NON-CENTRE MEMBERS ATTENDING TRAINING WORKSHOPS

MENTORING PROGRAMS
5

MENTORING RELATIONSHIPS
92

MENTEES
70

MENTORS
64

% WOMEN HDRS AND ECRS IN FLEET HAVING A MENTOR
34%

MENTORING QUALITY SCORE OUT OF 5 STARS -
INDUSTRY AVERAGE IS 4.2
4.57

More at FLEET.org.au/alumni

FLEET members highly value the transferable communication skills they have developed at public-facing Centre outreach events.

Building future **science leaders**

FLEET is building Australia's scientific capacity by training the next generation of science leaders

All FLEET's students and young researchers receive excellent supervision, world-class training and professional development, setting them up to navigate diverse future career pathways.

FLEET is on a mission to develop the next generation of science leaders. In the nearly seven years since FLEET began, we have trained more than 100 students and early-career researchers who are now in diverse careers and using their FLEET training to be a force for change.

The Centre currently supports 56 higher degree by research (HDR) students and 43 postdoctoral researchers.

PhD students are strongly encouraged to have an associate supervisor from another FLEET node or research theme, which helps with the cross-pollination of ideas and development of collaborative projects and also provides an additional source of mentoring and support.

FLEET training in 2023 featured a larger than usual number of FLEET seminars (17 in total), leveraging international speakers visiting Australia.

In pursuit of the Centre's training and mentoring objectives, the team initiated the collection and analysis of data to assess the impact of FLEET on the development of emerging science leaders.

FLEET members express a keen appreciation for the training they receive, emphasising the development of crucial transferable skills. Notably, the significance of honing communication, networking and collaborative skills were highlighted during their time at FLEET – see case study p100.

In addition to this structured training, FLEET members logged over 800 hours of science outreach, across more than 100 outreach activities. This personal outreach experience has been confirmed by our members to be valuable career training for communicating science concepts to a wider audience.

FLEET members took the initiative to pursue their own external training on equity issues (an annual requirement for all Centre members), for example, on impact evaluation, men supporting gender equity, working with neurodivergent talent, and knowledge of Australia's First Peoples.

PHD SUBMISSIONS IN 2023

Congratulations to the 20 PhD candidates who submitted their thesis in 2023 (to March 2024), bringing to 67 the total number of PhD graduates from FLEET so far:

From Swinburne: Jack Muir and Mitchell Conway (who have both since taken up postdoc positions at CSIRO), Allan Pennings (postdoc at UOM) and Rishabh Mishra (postdoc position at UNSW). From RMIT: Patjaree Aukarasereenont (postdoc position at CSIRO), Nam Van Ho, Prashant Kumar, Sajinda Afrin, Yik-Kheng Lee and Yogesh Kumar. From Monash: Ben Lowe (postdoc position in the Czech Republic), Phat Nguyen (researcher at Next Ore), Matt Gebert, Mitko Oldfield, Qile Li and Yi-Hsun Chen. From UOW: Abdulhakim Bake (postdoc position at Griffith). From UNSW: Maedehsadat Mousavi, Zhanning Wang and Zeb Krix.

Jack Muir
Swinburne

Mitchell Conway
Swinburne

Allan Pennings
Swinburne

Rishahb Mishra
Swinburne

Patjaree Aukarasereenont
RMIT

Prashant Kumar
RMIT

Sajinda Afrin
RMIT

Yik-Kheng Lee
RMIT

Yogesh Kumar
RMIT

Benjamin Lowe
Monash

Phat Nguyen
Monash

Matt Gebert
Monash

Mitko Oldfield
Monash

Qile Li
Monash

Yi-Hsun Chen
Monash

Abdulhakim Bake
UOW

Maedehsadat Mousavi
UNSW

Zhanning Wang
UNSW

Zeb Krix
UNSW

FLEET members sought out external training on the following:

- Career planning (e.g. identifying gaps and limitations to career progression)
- Commercialisation (e.g. intellectual property, pathways to commercialisation)
- Leadership (environmental, social and corporate governance, leadership presence, Diploma of Leadership and Management)
- Data protection and privacy
- Ethics and professional conduct.

> Regarding communication skills, I am confident I can talk to anyone from little children to CEOs because of all the cold calling and translation training I've done within FLEET, giving me the skills and confidence to talk to these audiences.
>
> **DR SASCHA HOINKA (SWINBURNE)**
> *FLEET Research Fellow*

FLEET's legacy will be:

- New, highly-trained members of Australia's next generation of science leaders
- Researchers trained in the electronics of tomorrow.

STRATEGIC PRIORITIES

- Develop world-class training and mentoring programs
- Establish Centre succession planning (see **Strategic Plan p106**)
- Facilitate opportunities for research collaboration
- Establish a collaborative culture within the Centre
- Facilitate opportunities for career development in industry
- Identify opportunities for members to be recognised.

To help understand the impact of FLEET training for its members, we have begun analysing training evaluation data and asking both Centre alums and existing FLEET members what they valued most from their time at FLEET. In the case of alums, we ask how this has influenced their career pathways or benefited them in their new roles.

Perhaps surprisingly, surveying indicates that while all FLEET members and alums value what they consider impeccable scientific training at FLEET, their dominant reflection of their time at FLEET, and what they consider of greatest value to their new careers, was their broad set of transferable skills gained from varied training opportunities.

A strong theme emerging in the data is that these highly-valued transferable skills were enabled by what by FLEET members perceive as a sense of community that provided a support network and sense of belonging.

Self-organised ECR workshop focusing on profile building, science communication, mental wellbeing and academic writing

FLEET SEMINARS

In 2023, FLEET significantly broadened its seminar series by hosting a larger than usual number of sessions, facilitated by the participation of several international speakers eager to share their research with the scientific community in Australia.

In line with the Centre's commitment to creating opportunities for ECRs and students to showcase their work, FLEET had the opportunity of welcoming back an alum who visited Australia, Dr Iolanda Di Bernado, offering a comprehensive update on her ongoing research at IMDEA Nanociencia in Spain.

These seminars provided valuable insights into the scientific advancements in other areas of the world and also emphasised the connections and engagement within the community.

Where appropriate, seminars were conducted in collaboration with other organisations, including seminars on:

- Magnetic skyrmions with the Australian Institute of Physics
- Nonreciprocal reflections and transmission and spin dynamics with the Monash School of Physics and Astronomy
- Scientists' value systems with the ARC Centre of Excellence in Synthetic Biology (CoESB; see below)
- Two research translation topics with the ARC Centre for Engineered Quantum Systems (EQUS; see below)
- Monolayer TMDs, interacting electron systems and solid-state cubits with the UNSW School of Physics.

With internal surveying having identified an appetite for more translation training, we sought the expertise of FLEET Translation Manager Dr Michael Harvey to arrange two more translation seminars in collaboration with EQUS, on identifying new pathways to research commercialisation, and effectively influencing government and science policy.

Delivering on a commitment to investigate ethical issues that could be encountered in future careers in science, FLEET sourced external expertise to run three relevant training sessions:

- Investigating responsible innovation with Dr Chris Browne (ANU)
- Finding strategies to personally encourage a more-inclusive culture in STEM workplaces with Winitha Bonney AM
- Understanding how scientists' value systems support or undermine impactful research with Prof Wendy Rogers (CoESB).

These seminars cumulatively attracted an audience of 388 people with 31 participants from outside the Centre.

FLEET's 'transpacific' series of colloquia on condensed-matter and cold-atom physics was expanded in 2023 to encompass European researchers. Seven colloquia in 2023 exposed members to leading international research in topics from polariton lasers and non-Hermitian topology to light–matter interactions and nanophotonics. See p71 for more.

CRITICAL SKILLS FOR FUTURE SCIENCE LEADERS

For future success as the next generation of science leaders, FLEET aims to help early-career researchers:

- Improve their ability to communicate and engage with varied audiences about their research, its meaning and value
- Gain high-level scientific and technical knowledge in their area of specialisation
- Understand the value of their research to their field of expertise, the goals of the organisation they work with, and its broader societal implications
- Develop a good professional network to help solve problems and build collaborative research efforts.

FLEET TRAINING IN 2023 FEATURED:

- 17 FLEET seminars
- 9 joint seminars
- 2 research translation seminars
- 7 US-Aust transpacific and EU-Aust colloquia
- 3 training sessions investigating potential ethical issues in a STEM career
- InSTEM conference on equity and diversity: 5 FLEET members and alums
- ECR and student workshop at UNSW, organised by the FLEET ECR Working Group
- Meet FLEET industry and academia event – see p28
- Expanded cross-Centre mentoring program, involving a total pool of 340 mentors and mentees – see p98
- Involvement of FLEET ECRs in all Centre governance committees.

> "We get to meet and talk to people who are successful in their field, because we're part of the same Centre. It makes you feel they are less mysterious, less 'higher up'. You [FLEET] don't put them up on a pedestal and then be afraid to approach them.
>
> **YIK-KHENG LEE**
>
> *FLEET Research Fellow*

Inclusive STEM workplace training with Winitha Bonney AM

2023 HIGHLIGHTS

- Running 11 training and development events for FLEET members, including:
  - 5 research and professional development courses
  - 3 ethical, equity, diversity and inclusion training sessions
  - 3 industry-engagement workshops.
- Launching the new cross–ARC Centre of Excellence mentoring program to significantly expand mentoring options for members (see this page)
- Expanding FLEET's successful transpacific colloquia series to include Europe-based speakers
- Gathering almost 80 researchers to discuss the future of electronic materials research in Australia (FEMRA 2023 see p71)
- Continuing the traditional Gordon Godfrey workshop at UNSW
- Sponsoring FLEET-Europe workshop on transport in exciton condensates and exciton insulators with partner organisation University of Camerino.

> Centres like FLEET not only work for solving the particular problems stated in their mission statements but also serve as the fertile fields for producing bright talent for the future. There is no better investment for a nation than creating a problem-solving, educated and enlightened lot of people ready to tackle the future challenges.
>
> **WAFA AFZAL**
> *FLEET alum*

EXPANSION OF THE FLEET MENTORING PROGRAM

A new expanded mentoring network in 2023 vastly increases the experience pool available for ECRs and others in 12 participating ARC Centres providing:

- Structured mentoring with ongoing support and oversight
- Access to a range of resources and peer-mentoring groups
- A large (300+), diverse pool of mentors and mentees for both researchers and professional staff.

Allowing members of the participating centres to access mentors in other centres significantly increases the pool of experiences and skills on offer.

"We are excited to see the connections which evolve from this initiative," says FLEET COO Dr Tich-Lam Nguyen. "This truly is a unique opportunity for participants to connect with researchers from 12 Centres of Excellence across a wide range of humanities, social sciences and STEM fields".

It's up to each mentoring pair to decide how much time to invest, but the best connections will typically involve monthly communication, via whatever channel suits.

In addition to high-quality research, a shared objective of all ARC Centres is to build Australia's future scientific workforce. Mentoring has been a vital component of this process, with benefits in skill enhancement and career progression and work–life balance.

Mentoring has proven valuable for all participants, with feedback from all centres' past mentoring programs confirming value for mentors as well as mentees.

The program continues to leverage the Melbourne-founded Mentorloop management platform, which has previously been used successfully by FLEET to

> My mentor shared tips and tricks on how to prepare for a job hunt, how to grow a network in the industry, how to write a CV. This was precious because, usually, we don't get such insight from people within academia.
>
> **FLEET MENTEE**

> I will never forget that my supervisor used to introduce me as a postdoc that was working *with* him, not *for* him. They are still my mentors when it comes to career choices etc.
>
> **DR IOLANDA DI BERNARDO (LEADING EDGE GRADUATE)**
>
> *Previously Research Fellow (Monash), now Fellow at IMDEA Nanociencia, Universidad Autónoma de Madrid and FLEET Scientific Associate Investigator*

allow structured mentoring support and oversight, as well as providing resources for mentees and mentors.

The cross-Centre program complements FLEET's four other mentoring programs, including industry mentoring, ECR mentoring, Women in FLEET, and academic mentoring.

The expanded mentoring program currently supports:

- 100 FLEET members participating across five mentoring programs
- 64 FLEET mentors, 70 FLEET mentees and 21 external mentors for FLEET members
- a mentoring quality score (4.57/5) well above industry benchmark.

The new collaboration currently includes the following other ARC Centres of Excellence (with capacity for new centres to join as they come online): All Sky Astrophysics in 3D, Automated Decision Making and Society (ADMW+S), Children and Families Over the Life Course, Dark Matter Particle Physics, The Digital Child, Engineered Quantum Systems (EQUS), Gravitational Wave Discovery (OzGrav), Innovations in Peptide and Protein Science (CIPPS), Plant Success in Nature and Agriculture, Synthetic Biology (CoESB) and Transformative Meta-Optical Systems (TMOS).

MENTOR STATISTICS		PARTICIPATION %	TOTAL
Chief investigators	10	50%	20
Partner investigators	3	13%	23
Scientific associate investigators	18	46%	39
Research fellows	18	42%	43
HDR students	21	38%	56
Centre business team	6	55%	11
Alumni & external collaborators	24	N/A	N/A

IN 2024 FLEET WILL:

- Continue the series of FLEET seminars
- Provide ongoing opportunities for students and ECRs to present their work
- Complete evaluation of FLEET's strategic goal of developing the next generation of science leaders
- Take advantage of the five-COE Better Futures Innovation Challenge to further develop FLEET members' translation skills and help them forge links with industry partners – see p27.

WHERE ARE THEY NOW?

FLEET alums are in diverse roles, including:

- Research scientists in industry and academia
- Project and business managers at other research centres and higher education institutions
- Scientific journal editors – Nature Research (publishing)
- Financial crime management
- Business and financial data analytics.

More at FLEET.org.au/alumni

FLEET alums and members value soft skills and community

It is not just technical and scientific skills that set up FLEET graduates for future career success

CASE STUDY

Surveying alums and current members reveals the impact of technical and transferable skills gained in the Centre.

FLEET is on a mission to develop the next generation of science leaders. In the nearly seven years since FLEET began we have trained over 100 researchers now in diverse careers

But it is not just their impeccable scientific training that they value from their time at FLEET.

To help understand the impact of FLEET training for its members, we have surveyed alums to find what they valued most from their time at FLEET and how this has influenced their career pathways and new roles.

Technical training was definitely crucial, and as one alum pointed out it also helped them develop confidence in their abilities.

But FLEET alums perceive their most important skills gained at FLEET to be transferable or professional skills such as communication, networking, translation and collaboration, and a broad understanding of the research ecosystem.

A strong theme emerging in survey data is that these highly-valued transferable skills were enabled by a sense of community, a strong support network, and a sense of belonging or common purpose.

"It's a feeling that FLEET members belong to a family, a ready-made network of experts and expertise they felt comfortable to reach out to for help or advice from," says FLEET coordinator Dr Jason Major. "It influenced participation in training programs and enabled strong relationships, networks and collaborations that enhanced leadership abilities and confidence in their own knowledge and abilities."

> With the [scientific] training gained at FLEET, I am not as hesitant any more. to embark on a completely new research direction, and I'm more confident about my own expertise and knowledge … and belief in my abilities to conduct projects independently.
>
> **DR PAVEL KOLESNICHENKO**
> *FLEET alum*

> The thing I enjoyed most about FLEET, other than the technical aspects of my work, was the sense of community, support for the members as well as the ample opportunities provided to gain exposure to various experiences, information and skill-up experiences.
>
> **DR HAREEM KHAN**
> *FLEET alum*

> There are very few communities that can give you a sense of belonging. I think FLEET has done this very successfully. I somehow feel connected with other FLEETers and I think this will continue even after FLEET has dissolved.
>
> **DR SEMONTI BHATTACHARYYA**
> *FLEET alum*

> Because of that sense of FLEET community, you didn't need to actually know someone to approach them. And that was the thing I enjoyed about FLEET – that because we are part of FLEET, we are going to help each other.
>
> **DR HAREEM KHAN**
> *FLEET alum*

The sense of community extended to a feeling of equity where all members, no matter their position or role, could be approached, and FLEET members felt comfortable in doing so – a sentiment also reinforced by discussions with current members.

> Within FLEET we have got to meet and talk to successful people in their field because we are part of the same Centre. It makes us feel these high-level experts are less mysterious, less 'higher up' than me. FLEET doesn't put these people on a pedestal, which would make us afraid to approach them.
>
> **DR YIK-KHENG LEE**
> *FLEET member*

FLEET alums and members felt they'd gained a valuable, holistic understanding of the research ecosystem that affected how they think about science and its impact, their careers, and even life itself.

> Interacting not just with academics, but with people from industry and wider research community (e.g. ANSTO, or other Centres of Excellence), and hearing about research that is happening all over the place, completely pivoted the way I thought about possible future jobs.
>
> **MATT GEBERT**
> *FLEET member*

> Every talk, every discussion, every workshop, every presentation, each annual conference added something to my knowledge and shaped my way of thinking, not just in 'science terms' but life in general.
>
> **WAFA AFZAL**
> *FLEET alum*

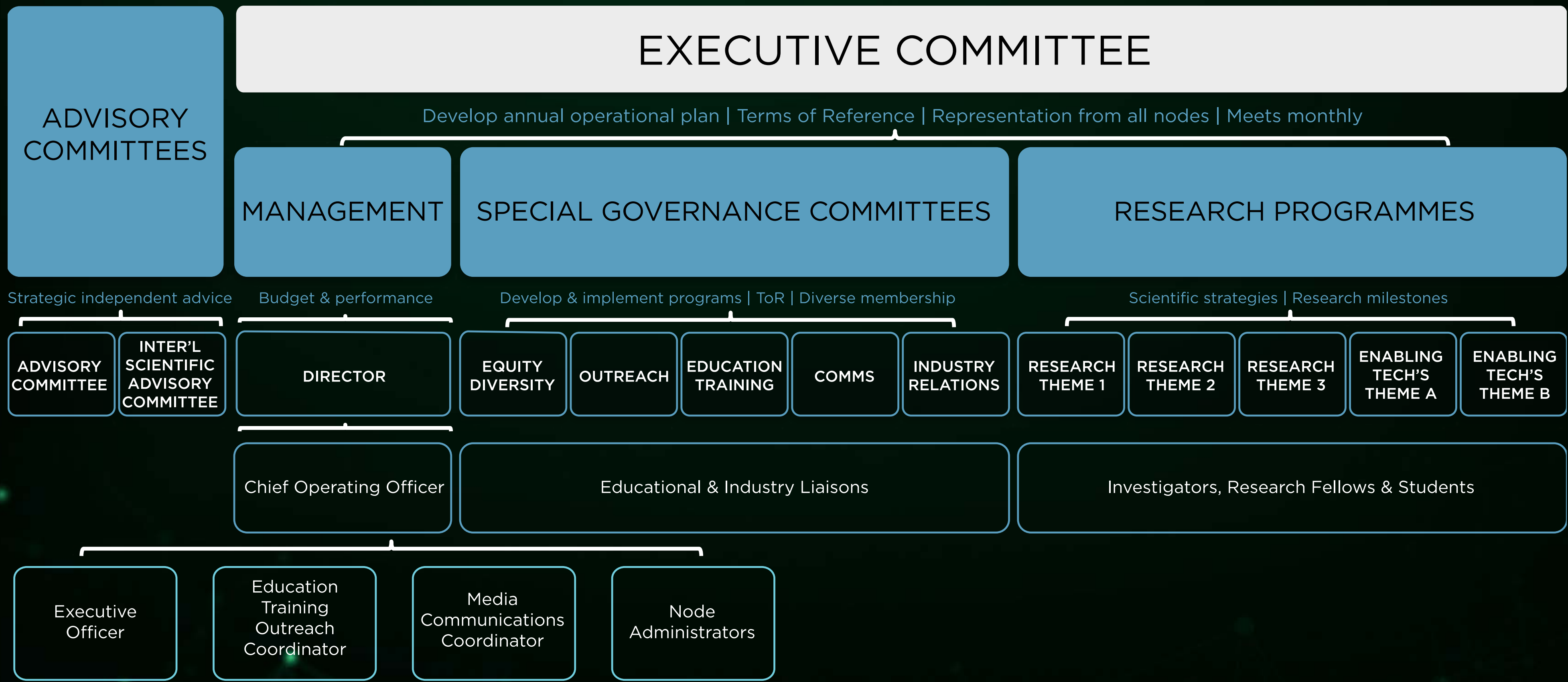
> While the technical training I developed in my PhD has been incredibly useful for my postdoc, I think understanding the landscape and how different areas of physics can be used in technology has been one of the most insightful lessons.
>
> **FLEET ALUM**

INSIDE FLEET

FLEET creates a work environment that develops its people and also values the contributions of individual members

- → **GOVERNANCE**
- → **FLEET EXECUTIVE TEAM**
- → **FLEET BUSINESS TEAM**

GOVERNANCE



ADVISORY COMMITTEES
EXECUTIVE COMMITTEE
Develop annual operational plan | Terms of Reference | Representation from all nodes | Meets monthly
MANAGEMENT
SPECIAL GOVERNANCE COMMITTEES
RESEARCH PROGRAMMES
Strategic independent advice
Budget & performance
Develop & implement programs | ToR | Diverse membership
Scientific strategies | Research milestones
ADVISORY COMMITTEE
INTER'L SCIENTIFIC ADVISORY COMMITTEE
DIRECTOR
EQUITY DIVERSITY
OUTREACH
EDUCATION TRAINING
COMMS
INDUSTRY RELATIONS
RESEARCH THEME 1
RESEARCH THEME 2
RESEARCH THEME 3
ENABLING TECH'S THEME A
ENABLING TECH'S THEME B
Chief Operating Officer
Educational & Industry Liaisons
Investigators, Research Fellows & Students
Executive Officer
Education Training Outreach Coordinator
Media Communications Coordinator
Node Administrators

Advisory Committee

FLEET's Advisory Committee helps the Executive Committee develop FLEET's strategic plan, which sets out how the Centre will meet its goals, in particular in creating linkages with industry, academia and government.

The Advisory Committee:

- Reviews FLEET's Annual Operating Plan
- Provides recommendations on financial management
- Provides recommendations on general management and operation, to ensure the Centre achieves its objectives.

ADVISORY COMMITTEE MEMBERS

Dr An Chen
IBM Research

Prof Andrew Peele
Australian Synchrotron, Australia

Prof Ellen Williams
University of Maryland, USA

Prof Joanna Batstone
Monash Data Futures Institute, Monash University

Prof Luigi Colombo
University of Texas, Dallas

Prof Michael Ryan
Monash University

Dr Steven Duvall
Semiconductor Sector Service Bureau

“I'm really impressed by FLEET. I think it's been really well organised, really well run and I think it's a model for other centres.

DR STEVE DUVALL
FLEET Advisory Committee

International Scientific Advisory Committee

FLEET's International Scientific Advisory Committee provides independent scientific advice to FLEET investigators, both directly and through the Centre director.

The International Scientific Advisory Committee:

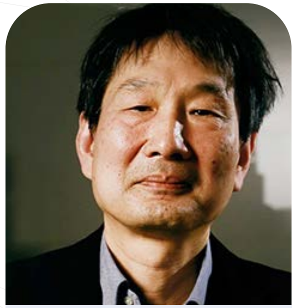
- Advises on the scientific directions of FLEET
- Benchmarks the quality of FLEET research against international standards.

INTERNATIONAL SCIENTIFIC ADVISORY COMMITTEE MEMBERS

Prof Ali Yazdani
Princeton University, USA

Dr Esther Levy
Advanced Materials Technologies

Prof Francois Peeters
University of Antwerp



Prof Hidenori Takagi
Max Planck Institute for Solid State Research, Stuttgart

Sir Kostya Novoselov
National University of Singapore

Sir Michael Pepper
University College London, UK

Prof Wolfgang Ketterle
Massachusetts Institute of Technology, USA

STRATEGIC PLAN

GOAL	MEASURE
1. ENABLE FRONTIER SCIENTIFIC DISCOVERIES	
1.1 Realise topologically-protected dissipationless transport of electrical current at room temperature, and novel devices based on the ability to switch on and off this dissipationless current	Project milestones and research outputs
1.2 Demonstrate excitonic dissipationless transport at elevated temperatures	Project milestones and research outputs
1.3 Investigate and realise systems that exhibit dissipationless transport by dynamically driving the systems out of equilibrium to explore new paradigms in electronics	Project milestones and research outputs
2. DEVELOP NEXT GENERATION OF SCIENCE LEADERS	
2.1 Develop world-class training & mentoring programs	Number of: • Participating members • External mentors • Research/professional development courses • Members and non-members participating in Centre training workshops • Mentoring programs • Organisational links in mentoring and training programs
2.2 Establish Centre succession planning for the centre	Established plan
2.3 Facilitate opportunities for research collaboration	Number of: • Travel grants facilitating collaboration • FLEET-wide colloquia, research seminars and workshops • Collaborative visits by FLEET partners • Intra-Centre expertise exchanges • New organisations collaborating with FLEET
2.4 Establish a collaborative culture within the Centre	Number of: • Travel grants facilitating collaboration • FLEET-wide colloquia, research seminars and workshops • Collaborative visits by FLEET partners • Intra-Centre expertise exchanges • New organisations collaborating with FLEET
2.5 Facilitate opportunities for career development in industry	Number of internship placements
2.6 Identify opportunities for members to be recognised	Number of awards and grants received by members for their scientific/leadership achievements
3. FACILITATE PARTNERSHIP DEVELOPMENT	
3.1 Establish international partnerships	Number of: • New research organisations collaborating with FLEET • Collaborative visits between members and collaborating organisations • Organisational links in training and mentoring programs • Organisational links in education and outreach programs
3.2 Establish links to industry and end users	Number of: • Briefings to end-users/industy • Internship placements with industy collaborators
3.3 Create a network to commercialise FLEET discoveries	Number of: • Relationships with end-users • Industry engagement workshops

For the full FLEET Strategic Plan go to FLEET.org.au/strategic-plan

4. FOSTER EQUITY / DIVERSITY IN STEM	
4.1 Foster a culture of equity and inclusiveness	Number of positive responses to annual surveys Level of compliance of all events organised/supported by FLEET with Centre's Equity and Diversity guidelines Increased participation of required training on equity, diversity and inclusion topics Awareness to recognise unacceptable behaviour and pathways to report
4.2 Increase diversity among all cohorts of researchers	Increased number of researchers and HDR students from marginalised groups across FLEET Level of compliance of FLEET HR policy in all Centre recruitments
4.3 Establish career support initiatives for women in FLEET and members with caring responsibilities	Gender ratio of ECRs staying in FLEET and science careers beyond FLEET Increased participation of FLEET researchers with family/carer responsibilities in FLEET/external events
4.4 Establish a women-specific mentoring network	Increased uptake of mentoring opportunities by women in FLEET
5. PROMOTE PUBLIC AWARENESS AND LITERACY OF FLEET SCIENCE	
5.1 Contribute to the scientific literacy and understanding of STEM and FLEET science among primary and secondary students and teachers	Evaluation of the understanding and literacy at school-based engagement events
5.2 To raise awareness of FLEET research among the general public	Evaluation of awareness at public engagement events Relevant social media metrics to assess engagement
6. FACILITATE EFFECTIVE COMMUNICATION	
6.1 Support Centre strategic goals through internal communication using tools such as monthly newsletters	Improvement in internal newsletter readership
6.2 Engage with scientific research community through research stories published on key online science platforms and stakeholders' newsletters	Number of: • Research stories • Newsletter audience
6.3 Promote FLEET research and scientific literacy to public through web content and social media	Number of: • Social media audience reached on priority channels (Twitter, Facebook) • Mainstream media articles • Mentions of FLEET research in all media channels
6.4 Engage with key partners	Number of • Briefings to government agencies and NGOs • Public presentations annually
6.5 Empower FLEET members to communicate their own scientific work	Number of: • Non-peer reviewed articles • Members discussing their science on social media • Members presenting their research in a public forum • ECR and student members participating in Three-Minute Thesis, FameLab, Science in the Pub, and similar
6.6 Push the boundaries of what we're doing in communications, seeking and championing communications "best practice"	Number of new initiatives each year

Executive Committee

FLEET's Executive Committee oversees strategic plans for the Centre in accordance with the Australian Research Council (ARC) Funding Agreement and agreements with the Centre's collaborating organisations.

The committee's responsibilities include:

- Overseeing general management and operation of the Centre
- Properly allocating funding
- Approving Centre activities
- Approving Centre intellectual property ownership
- Approving any amendments to the Centre budget and research program
- Promoting interactions between participants and partners across nodes and institutions
- Solving problems in the successful execution of the Centre's mission
- FLEET's Executive team comprises leaders of research themes and nodes, and committee chairs.

MICHAEL FUHRER, DIRECTOR

Michael is a pioneer in the study of electronic properties of two-dimensional (2D) materials, with extensive experience establishing and managing large, interdisciplinary research teams in Australia and the USA.

Michael directs implementation of FLEET's vision and mission and coordinates the three Research themes and two Enabling technologies.

With FLEET's Executive team, Michael implements the Centre's strategic plan, directing research, technology transfer, training and mentorship, and outreach.

An accomplished communicator, Michael represents FLEET's work to the research community, government, students, media and the public, and coordinates Centre submissions on government policy.

Michael is former director of the Monash Centre for Atomically Thin Materials and the Center for Nanophysics and Advanced Materials (University of Maryland).

TICH-LAM NGUYEN, CHIEF OPERATING OFFICER

Tich-Lam manages FLEET's operations and its business team. She is responsible for the Centre's financial and operational effectiveness and overseeing activities contributing to the development and delivery of its strategic goals.

Tich-Lam has a PhD in Chemistry from RMIT University and a Master of Management from the Melbourne Business School.

She has 18 years' experience as a research centre manager and a nanoscience researcher. She's passionate about creating equity in STEM and impactful opportunities by developing innovative collaborations and connecting expertise.

Alex Hamilton

Deputy Director,
Leader
Research theme 1

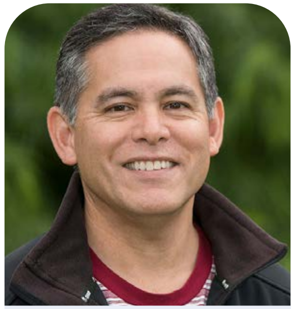
UNSW

Elena Ostrovskaya

Deputy Chair,
Equity and Diversity Committee
Leader Research theme 2

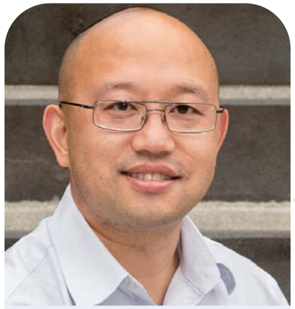
ANU

EXECUTIVE COMMITTEE



Kris Helmerson
Leader, Research theme 3
Monash

Xiaolin Wang
Leader, Enabling technology A
UOW



Lan Wang
Leader, Enabling technology B (until March)

Oleh Klochan
Leader, Enabling technology B (from April)
UNSW

Agustin Schiffrin
Chair, Outreach
Monash

Jeff Davis
Chair, Equity and Diversity
Swinburne

Kirrily Rule
Chair, Communications
ANSTO

Matthew Davis
Director, FLEET Translation Program
UQ

Sumeet Walia
Co-chair, Industry Relations
RMIT

Susan Coppersmith
Chair, Education and Training
UNSW

Torben Daeneke
Co-chair, Industry Relations
RMIT

Business team

Tich-Lam Nguyen

Chief Operating Officer

Tich-Lam oversees FLEET's financial and operational effectiveness, aimed at delivering the Centre's strategic goals.

Nandhini Nehru

Executive Officer

Nandhini coordinates KPI and budget reporting across FLEET's seven nodes and provides administrative support to the Executive and governance committees. From Sept 2023.

Tenille Ibbotson

Executive Officer

Tenille coordinates KPI and budget reporting across FLEET's seven nodes and provides administrative support to the Executive and governance committees. To August 2023.

Catherine Taylor

Node Administrator

UNSW

Catherine supports FLEET operations and financial reporting at UNSW.

Kath Tajer

Node Administrator

UNSW

Kath supports FLEET operations and reporting at UNSW and provides administrative support to node leader Prof Alex Hamilton.

Tatiana Tchernova

Node Administrator

Swinburne

Tatiana provides administrative support and coordinates KPI reporting, as well as supporting node leader Prof Chris Vale.

> "The support FLEET has provided me with over the years, since I was an undergrad to now as a PhD student has been invaluable.
>
> **KRITTIKA KUMAR, (UNSW)**
>
> *FLEET PhD student*

Errol Hunt

Senior Communications Coordinator

Errol coordinates FLEET's communications strategies, and communicates Centre mission and outcomes within FLEET, to the scientific community, to potential end users and to the public via media.

Jason Major

Senior Training and Outreach Coordinator

Jason leads FLEET's education and training missions, student recruitment, career development programs, internship placement and outreach programs.

Nicci Coad

Node Administrator

RMIT

Nicci coordinates reporting of KPIs and budgets across the FLEET nodes and provides administrative support to node leader A/Prof Lan Wang and the RMIT team. To July 2023.

Elizabeth Klaric

Node Administrator

RMIT

Elizabeth coordinates reporting of KPIs and budgets across the FLEET nodes and provides administrative support to node leader Prof Jared Cole and the RMIT team. From August 2023.

Equity and Diversity Committee

FLEET fosters a culture of inclusiveness and works to promote diversity across the Centre.

FLEET's Equity and Diversity Committee sets and monitors the Centre's equity priorities, monitors our progress and tracks staff culture via surveys, and learns from equity best practice across the science sector.

See Equity at FLEET.

> Having my family at conferences was something I'd never done before FLEET, but I now like to do it more and more often. So that's probably had a long-term impact on how I involve my family in my scientific activities.
>
> **DAVID CORTIE (UOW)**
>
> *Scientific Associate Investigator*

EQUITY AND DIVERSITY COMMITTEE MEMBERS

Jeff Davis
Committee Chair
Swinburne

Elena Ostrovskaya
Committee Deputy Chair
ANU

Dimi Culcer
Chief Investigator
UNSW

Emma Laird
Research Fellow
UQ

Kris Helmerson
Chief Investigator
Monash

Matthew Davis
Chief Investigator
UQ

EQUITY AND DIVERSITY COMMITTEE MEMBERS

Meera Parish
Chief Investigator
Monash

Nicci Coad
Node Administrator
RMIT

Sumeet Walia
Scientific Associate Investigator
RMIT

> The diversity of a Centre like FLEET plays a role, as different approaches and ideas combine together to become a force for change. Centres like FLEET not only work for solving the particular research problems stated in their mission statements, but they also serve as the fertile fields for producing bright talent for the future.
>
> **WAFA AFZAL**
> *FLEET alum*

Tenille Ibbotson
Executive Officer
FLEET

Tich-Lam Nguyen
Chief Operating Officer
FLEET

Xiaolin Wang
Chief Investigator
UOW

Building future science leaders: Education and Training Committee

FLEET is building future Australian science leaders among the Centre's early-career researchers and higher degree by research students.

FLEET's Education and Training Committee sets the Centre's strategies and sponsorship priorities, checking progress and development requirements.

See Education at FLEET.

EDUCATION AND TRAINING COMMITTEE MEMBERS

Susan Coppersmith
Committee Chair
UNSW

Matthew Davis
Committee Deputy Chair
UQ

Jan Seidel
Chief Investigator
UNSW

Jason Major
Senior Training & Outreach Coordinator
FLEET

Jeff Davis
Chief Investigator
Swinburne

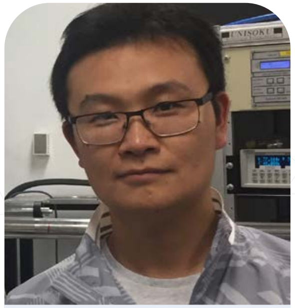
Jesper Levinsen
Scientific Associate Investigator
Monash

EDUCATION AND TRAINING COMMITTEE MEMBERS

Oleh Klochan
Chief Investigator
UNSW

Peggy Qi Zhang
Research Fellow
UNSW

Xiaolin Wang
Chief Investigator
UOW



Zhi Li
Scientific Associate Investigator
UNSW

> "FLEET's mentor and training programs have been incredibly valuable for me, and I have recently landed a post-doc position in Europe, which I'm not sure would have been possible without my (several) FLEET mentors.
>
> **FLEET MEMBER**

Spreading a passion for science: Outreach Committee

FLEET will promote public awareness and literacy of FLEET science and inspire more participation in science.

FLEET's Outreach Committee sets outreach strategy and determines appropriate outreach activities and public events to support.

See Engage with FLEET.

OUTREACH COMMITTEE MEMBERS

Agustin Schiffrin
Committee Chair
Monash

Nikhil Medhekar
Committee Deputy Chair
Monash

Angela White
Research Fellow
UQ

Chris Vale
Chief Investigator
Swinburne

Dimi Culcer
Chief Investigator
UNSW

Errol Hunt
Senior Communications Coordinator
FLEET

OUTREACH COMMITTEE MEMBERS

Feixiang Xiang
Research Fellow
UNSW

Gordon Luo
PhD student
UNSW

Jason Major
Education and Outreach Coordinator
FLEET

Joshua Gray
PhD student
RMIT

Julie Karel
Chief Investigator
Monash

Karina Hudson
Scientific Associate Investigator
UNSW

Matthew Davis
Chief Investigator
UQ

> “I have appreciated outreach opportunities – for example at schools – that wouldn't have existed outside of FLEET. This training in public speaking has allowed me to build my confidence.
>
> **FLEET MEMBER**

INSIDE FLEET

Sharing FLEET news and science: Communications Committee

FLEET's Communications Committee gathers information and leads on stories from diverse nodes, feeds these stories through to the communications coordinator, channels feedback from the nodes, and develops strategies to communicate FLEET research to the wider research community, partners, stakeholders, potential end users and the public.

See Engage with FLEET.

COMMUNICATIONS COMMITTEE MEMBERS

Kirrily Rule
Committee Chair
ANSTO

David Cortie
Committee Deputy Chair
ANSTO / UOW

Abigail Goff
Masters student
RMIT

Errol Hunt
Senior Communications Coordinator
FLEET

Jackson Smith
Scientific Associate Investigator
RMIT

Jared Cole
Chief Investigator
RMIT

COMMUNICATIONS COMMITTEE MEMBERS

Jeff Davis
Chief Investigator
Swinburne

Karina Hudson
Scientific Associate Investigator
UNSW

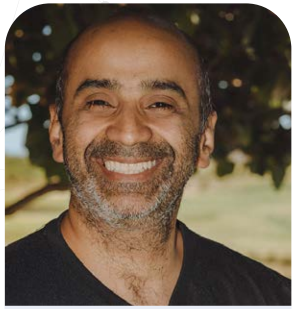
Kath Tajer
Node Administrator
UNSW

Kyle Boschen
PhD student
Swinburne

> “FLEET has allowed me to spread my research more widely, and attract more collaborators.
>
> **FLEET MEMBER**

Matt Reeves
Scientific Associate Investigator
UQ

Mitko Oldfield
PhD student
Monash



Nagy Valanoor
Chief Investigator
UNSW

> “FLEET has helped me in networking, introducing me to researchers outside of my own areas and providing real opportunities for collaboration.
>
> **FLEET MEMBER**

Research translation: Industry Relations Committee

FLEET's Industry Relations Committee's tasks are to:

- Ensure FLEET research outcomes are fed into affiliated and broader industries
- Coordinate efforts with other relevant Centre functions such as Education and the FLEET Translation Program
- Engage with current industrial partners and attract future industry partners
- Establish the ground for translation and eventual commercialisation of research outputs, with maximum benefit to the consumers.

See Research Translation.

INDUSTRY RELATIONS COMMITTEE MEMBERS

Sumeet Walia
Committee Co-Chair
RMIT

Torben Daeneke
Committee Co-Chair
RMIT

Errol Hunt
Senior Communications Coordinator
FLEET

Jian-zhen Ou
Scientific Associate Investigator
RMIT

Matthew Gebert
PhD student
Monash

Mitchell Conway
Research Fellow
Swinburne

Tich-Lam Nguyen
Chief Operating Officer
FLEET

Education and industry liaisons

FLEET works with specialised educational and outreach liaisons.

EDUCATION AND INDUSTRY LIAISONS

Andrew Hind
General Manager of Molecular Spectroscopy
Agilent Technologies

Camille Thomson
Australian Institute of Policy and Science

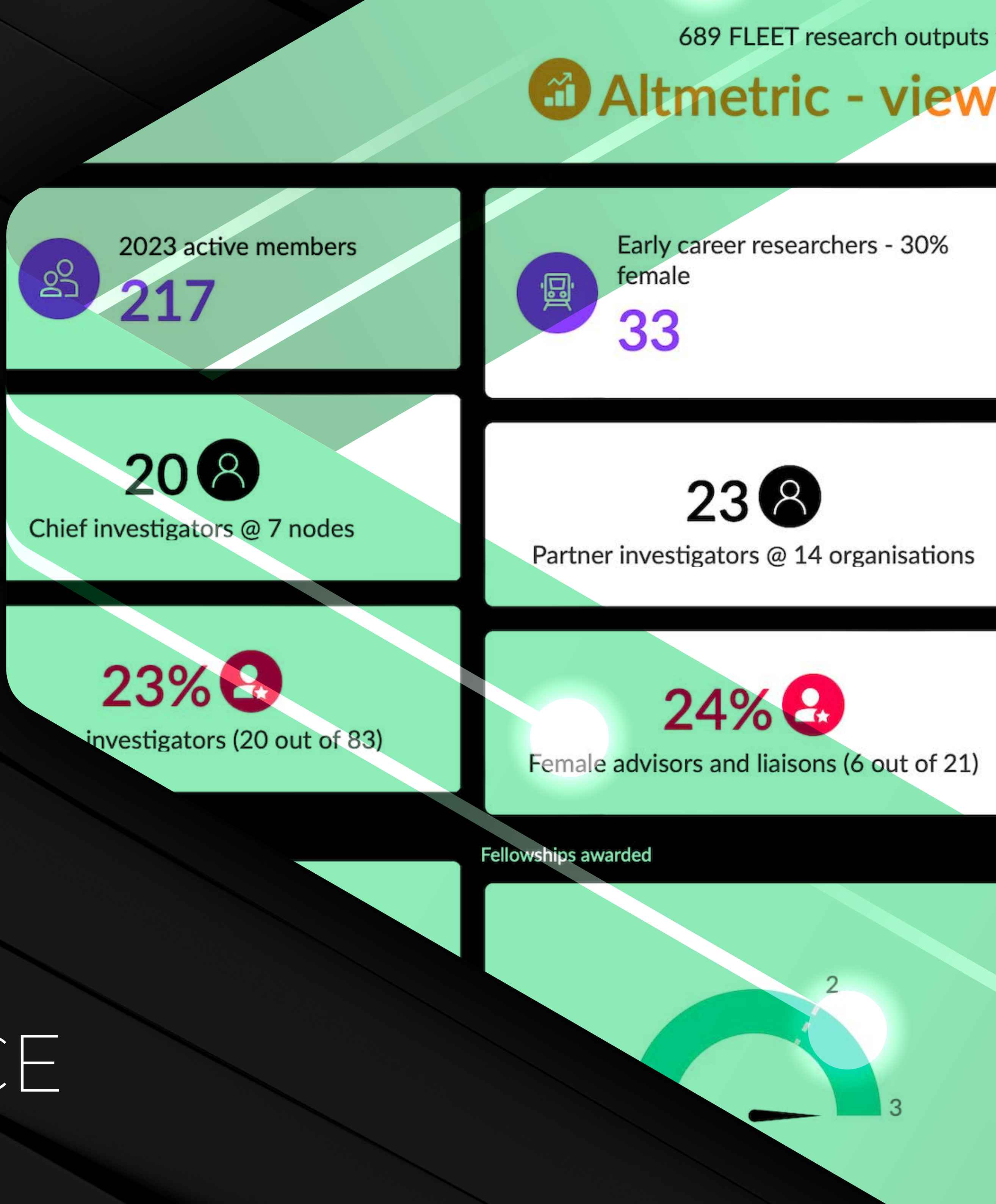
Chris Gilbey
CEO
Imagine Intelligent Materials Pty Ltd

Eroia Barone-Nugent
Australian Institute of Policy and Science

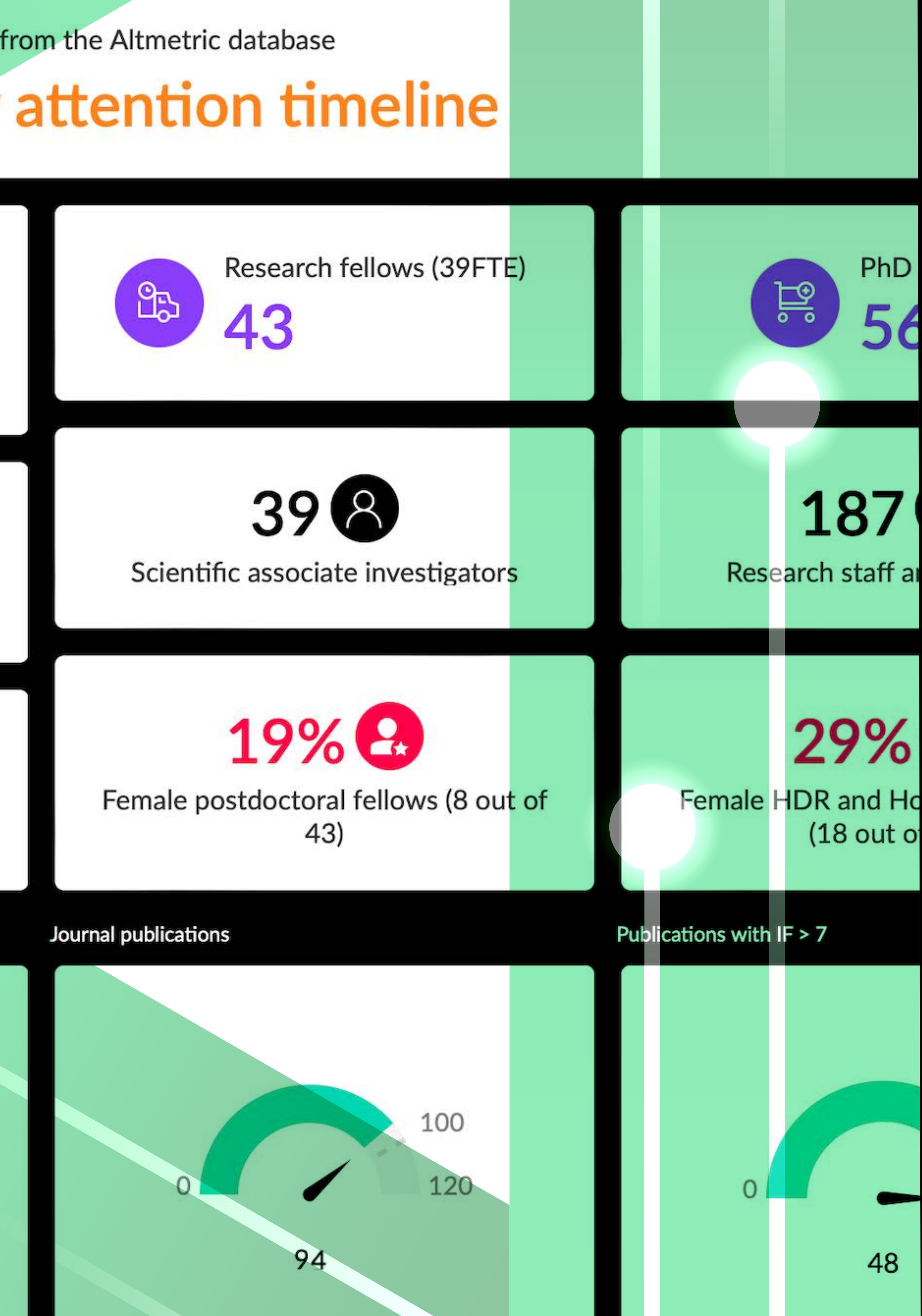
Jim Patrick
Chief Scientist and Senior Vice President Research and Applications
Cochlear Limited

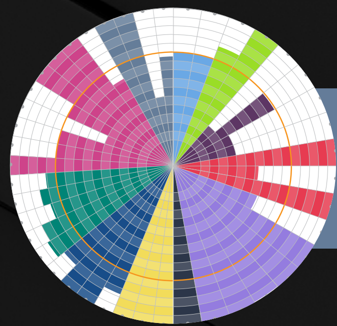
Mark Muzzin
CSIRO

Dr Toby Bell
Monash University



PERFORMANCE





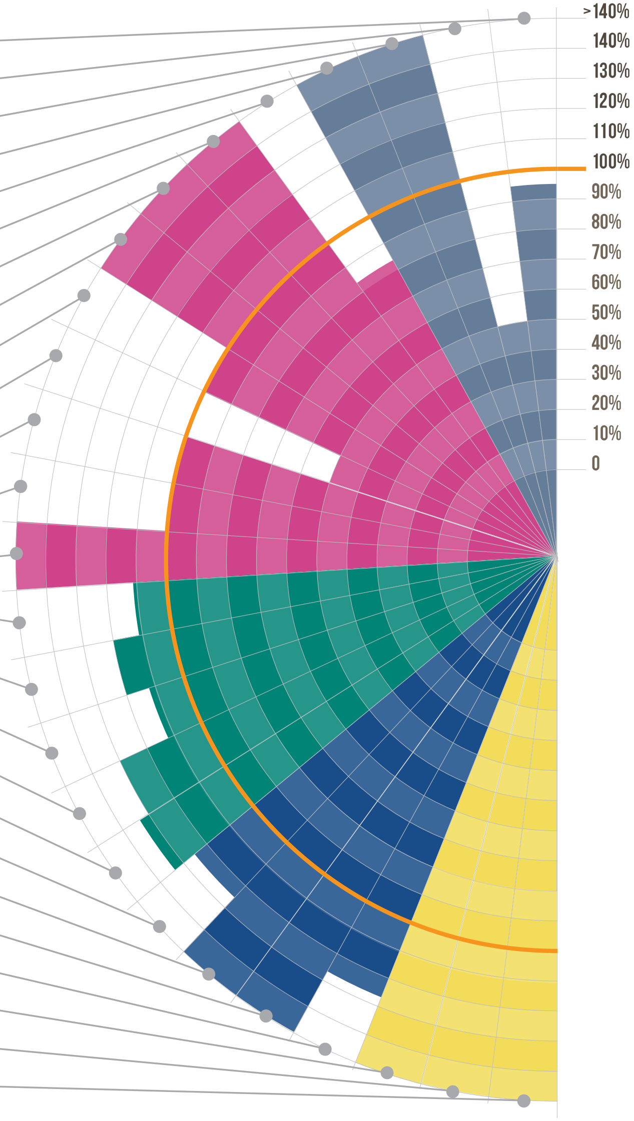
→ KEY PERFORMANCE INDICATORS

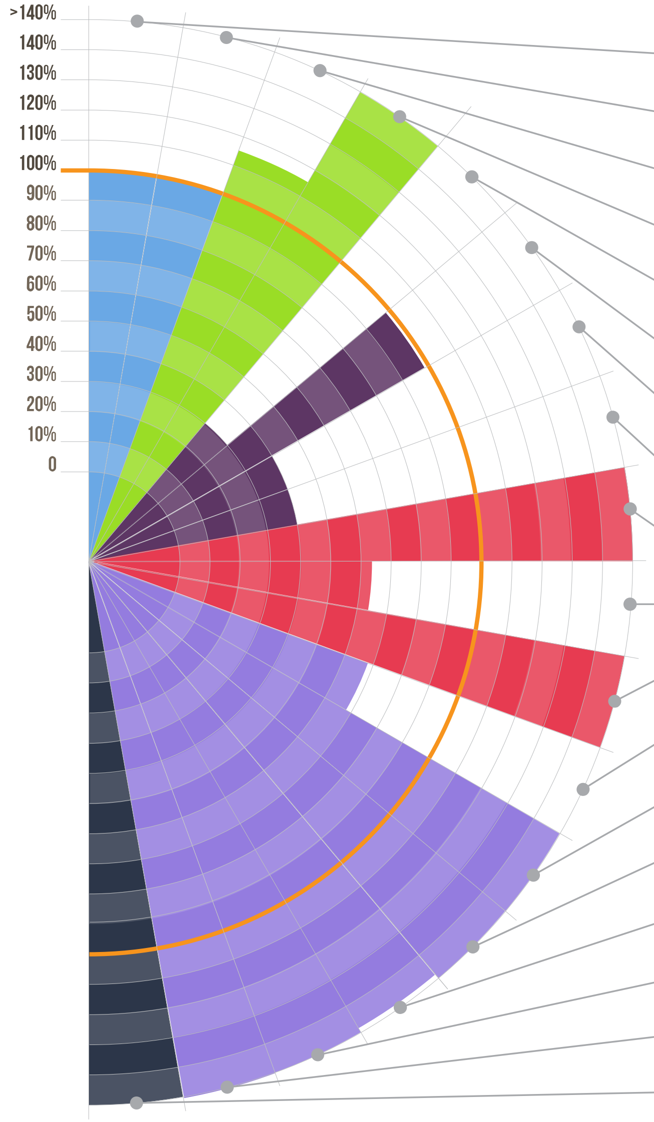
Key performance indicators

PERFORMANCE MEASURES

- Research Outputs
- Education and Training
- FLEET Research Personnel
- Mentoring
- Partnership Development Research engagement & outreach

STANDARD KPI	Target	Actual	% Met
Journal articles	100	94	94%
Patents applied	2	1	50%
Technical briefings presented to targeted industry groups	1	23	>140%
Publications in journals with IF >7	20	48	>140%
Research & professional development courses	6	5	83%
Training workshops on diversity and gender equity	1	2	>140%
Centre attendees at training workshops	500	1526	>140%
Non-Centre attendees at training workshops	300	530	>140%
Workshops held within Australia	2	2	100%
Workshops held outside Australia	2	1	50%
National symposia & conferences facilitated	1	1	100%
International symposia & conferences facilitated	1	1	100%
Industry engagement workshops held	1	3	>140%
Postdoctoral researchers (total FTE)	35	39	111%
Honours students (total)	5	6	120%
PhD students (total)	50	56	112%
Associate Investigators (total)	30	39	130%
PhD completions	15	20	133%
Mentoring programs offered by the Centre	4	5	125%
Mentors within the Centre	40	64	>140%
Mentors external to the Centre	10	21	>140%
FLEET members participating as mentees	55	70	127%
Organisational links in training and mentorship programs	5	17	>140%
Presentations to external stakeholders	30	57	>140%
New organisations collaborating with, or involved in, the Centre	8	17	>140%





% Met	Actual	Target	CENTRE SPECIFIC KPI
100%	30%	30%	Percentage of women HDRs in FLEET
100%	30%	30%	Percentage of women ECRs in FLEET
115%	46	40	Invited talks at international conferences
>140%	4	2	New fellowships awarded to CIs, ECRs and AIs
30%	3	10	International students and ECRs visiting FLEET
97%	29	30	Senior investigators - International visitors FLEET
40%	4	10	Chief investigators visiting partners
40%	6	15	ECR & HDR students visiting partners
>140%	15	10	Non-peer reviewed works by FLEET members
63%	189	300	Mentions of FLEET research in the media
>140%	6167	1500	Unique hits to Centre website, monthly average
68%	810	1200	Hours spent in outreach activities
>140%	4584	2000	Primary/secondary students reached in outreach activities
>140%	289	75	Primary/secondary teachers reached in outreach activities
137%	6829	5000	Public reached in outreach activities
>140%	28	10	Organisational links in education and outreach programs
>140%	25	10	End-user relationships established
>140%	13,191	3000	Other research income secured by Centre staff ('000)

PERFORMANCE MEASURES

- Gender equity
- Recognition
- Partnership development
- FLEET PR and Marketing
- Outreach
- New funding

Key performance indicators

FLEET PERFORMANCE PROGRESS 2023

STANDARD KEY PERFORMANCE INDICATORS FOR CENTRE OF EXCELLENCE				
Category	**Key Performance Indicators**	**Target 2023**	**Actual 2023**	**% Met**
Research Outputs	Journal articles	100	94	94%
	Patents applied	2	1	50%
	Technical briefings presented to targeted industry groups	1	23	>140%
	Publications in journals with IF >7	20	48	>140%
Education & Training	Research & professional development courses	6	5	83%
	Training workshops on diversity and gender equity	1	1	100%
	Centre attendees at training workshops	500	1526	>140%
	Non-Centre attendees at training workshops	300	530	>140%
	Workshops held within Australia	2	2	100%
	Workshops held outside Australia	2	0	0%
	National symposium & conferences facilitated	1	0	0%
	International symposia & conferences facilitated	1	2	>140%
	Industry engagement workshops to be held	1	3	>140%
FLEET Research Personnel	Postdoctoral researchers (total FTE)	35	39	111%
	Honours students (total)	5	6	120%
	PhD students (total)	50	56	112%
	Associate Investigators (total)	30	39	130%
	PhD completions	15	20	133%
Mentoring	Mentoring programs offered by the Centre	4	5	125%
	Mentors within the Centre	40	64	>140%
	Mentors external to the Centre	10	21	>140%
	FLEET members participated as mentees	55	70	127%
Partnership development	Organisational links in training and mentorship programs	5	17	>140%
Research engagement & outreach	Presentations to external stakeholders	30	57	>140%
	New organisations collaborating with, or involved in, the Centre	8	17	>140%

FLEET PERFORMANCE PROGRESS 2023

CENTRE-SPECIFIC KEY PERFORMANCE INDICATORS FOR FLEET				
Category	**Key Performance Indicators**	**Target 2023**	**Actual 2023**	**% Met**
Gender Equity	Percentage of women HDRs in FLEET	30%	30%	100%
	Percentage of women ECRs in FLEET	30%	30%	100%
Recognition	Invited talks at international conferences	40	46	115%
	New fellowships awarded to CIs, ECRs and AIs	2	4	>140%
Partnership development	International students and ECRs visiting FLEET	10	3	30%
	Senior investigators - International visitors to FLEET	30	29	97%
	Chief investigators visiting partners	10	4	40%
	ECRs & HDR students visiting partners	15	6	40%
FLEET PR & Marketing	Non-peer reviewed works written by FLEET members	10	15	>140%
	Mentions of FLEET research in the media	300	189	63%
	Unique hits to Centre website, monthly average	1500	6167	>140%
Outreach	Hours spent in outreach activities	1200	810	68%
	Primary/secondary students reached in outreach activities	2000	4584	>140%
	Primary/secondary teachers reached in outreach activities	75	289	>140%
	Public reached in outreach activities	5000	6,829	137%
	Organisational links in education and outreach programs	10	28	>140%
	End-user relationships established	10	25	>140%
New Funding	Other research income secured by Centre staff (thousands)	3000	13,191	>140%

PERFORMANCE

FLEET Peer-reviewed publications

1. Algarni, M.; Zhang, H.; Zheng, G.; Zhou, J.; Tan, C.; Albarakati, S.; Partridge, J.; Mayes, E. L. H.; Farrar, L.; Han, Y.; Wu, M.; Zhu, X.; Tang, J.; Wei, W.; Gao, W.; Ning, W.; Tian, M.; Wang, L. *Carrier and Thickness Mediated Ferromagnetism in Chiral Magnet* $Mn_{1/3}TaS_2$ Nanoflakes. Journal of Applied Physics **2023**, 133 (11), 113902. https://doi.org/10.1063/5.0119850. Impact Factor less than 4 #
2. Alosaimi, G.; Huang, C.; Sharma, P.; Wu, T.; Seidel, J. *Morphology-Dependent Charge Carrier Dynamics and Ion Migration Behavior of* $CsPbBr_3$ *Halide Perovskite Quantum Dot Films*. Small **2023**, 2207220. https://doi.org/10.1002/smll.202207220. Impact Factor >10 *
3. Ameen, M.; Jabbar, F.; Yang, D.; Irfan, M.; Krishnamurthi, V.; Parker., C. J.; Zuraiqi, K.; Le, T. C.; Spencer, M. J. S.; Daeneke, T.; Chiang, K. *Liquid Metal Alloy Catalysis – Challenges and Prospects*. ChemCatChem **2023**, e202300814. https://doi.org/10.1002/cctc.202300814. Impact Factor 4 to 7 *
4. Aoki, M.; Yin, Y.; Granville, S.; Zhang, Y.; Medhekar, N. V.; Leiva, L.; Ohshima, R.; Ando, Y.; Shiraishi, M. *Gigantic Anisotropy of Self-Induced Spin-Orbit Torque in Weyl Ferromagnet* Co_2MnGa. Nano Lett. **2023**, 23 (15), 6951–6957. https://doi.org/10.1021/acs.nanolett.3c01573. Impact Factor >10 # *
5. Atencia, R. B.; Xiao, D.; Culcer, D. *Disorder in the Nonlinear Anomalous Hall Effect of PT -Symmetric Dirac Fermions*. Phys. Rev. B **2023**, 108 (20), L201115. https://doi.org/10.1103/PhysRevB.108.L201115. Impact Factor less than 4
6. Bake, A.; Zhang, Q.; Ho, C. S.; Causer, G. L.; Zhao, W.; Yue, Z.; Nguyen, A.; Akhgar, G.; Karel, J.; Mitchell, D.; Pastuovic, Z.; Lewis, R.; Cole, J. H.; Nancarrow, M.; Valanoor, N.; Wang, X.; Cortie, D. *Top-down Patterning of Topological Surface and Edge States Using a Focused Ion Beam*. Nat Commun **2023**, 14 (1), 1693. https://doi.org/10.1038/s41467-023-37102-x. Impact Factor >10 # *
7. Bhalla, P.; Das, K.; Agarwal, A.; Culcer, D. *Quantum Kinetic Theory of Nonlinear Optical Currents: Finite Fermi Surface and Fermi Sea Contributions*. Phys. Rev. B **2023**, 107 (16), 165131. https://doi.org/10.1103/PhysRevB.107.165131. Impact Factor less than 4 *
8. Camley, R. E.; Livesey, K. L. *Consequences of the Dzyaloshinskii-Moriya Interaction*. Surface Science Reports **2023**, 78 (3), 100605. https://doi.org/10.1016/j.surfrep.2023.100605. Impact Factor >10 *
9. Causer, G. L.; Guasco, L.; Paull, O.; Cortie, D. *Topical Review of Quantum Materials and Heterostructures Studied by Polarized Neutron Reflectometry*. Physica Rapid Research Ltrs **2023**, 2200421. https://doi.org/10.1002/pssr.202200421. Impact Factor less than 4 # *
10. Chansky, A.; Efimkin, D. K. *Topological Hybrid Electron-Hole Cooper Pairing*. Phys. Rev. B **2023**, 108 (7), 075433. https://doi.org/10.1103/PhysRevB.108.075433. Impact Factor less than 4 *
11. Chen, L.; Zhao, W.; Wang, Z.; Tang, F.; Fang, Y.; Zeng, Z.; Xia, Z.; Cheng, Z.; Cortie, D. L.; Rule, K. C.; Wang, X.; Zheng, R. *Spin Reorientation Transition and Negative Magnetoresistance in Ferromagnetic* $NdCrSb_3$ *Single Crystals*. Materials **2023**, 16 (4), 1736. https://doi.org/10.3390/ma16041736. Impact Factor less than 4 # *
12. Chen, L.; Zhao, W.; Xing, K.; You, M.; Wang, X.; Zheng, R.-K. *Anomalous Hall Effect in Nd-Doped* $Bi_{1.1}Sb_{0.9}STe_2$ *Topological Insulator Single Crystals*. Phys. Chem. Chem. Phys. **2024**, 26 (3), 2638–2645. https://doi.org/10.1039/D3CP05850F. Impact Factor less than 4
13. Chi, Y.; Kumar, P. V.; Zheng, J.; Kong, C.; Yu, R.; Johnston, L.; Ghasemian, M. B.; Rahim, Md. A.; Kumeria, T.; Chu, D.; Lu, X.; Mao, G.; Kalantar-Zadeh, K.; Tang, J. *Liquid-Metal Solvents for Designing Hierarchical Nanoporous Metals at Low Temperatures*. ACS Nano **2023**, 17 (17), 17070–17081. https://doi.org/10.1021/acsnano.3c04585. Impact Factor >10 *
14. Choi, E.; Lee, J.; Anaya, M.; Mirabelli, A.; Shim, H.; Strzalka, J.; Lim, J.; Yun, S.; Dubajic, M.; Lim, J.; Seidel, J.; Agbenyeke, R. E.; Kim, C. G.; Jeon, N. J.; Soufiani, A. M.; Park, H. H.; Yun, J. S. *Synergetic Effect of Aluminum Oxide and Organic Halide Salts on Two-Dimensional Perovskite Layer Formation and Stability Enhancement of Perovskite Solar Cells*. Advanced Energy Materials **2023**, 13 (39), 2301717. https://doi.org/10.1002/aenm.202301717. Impact Factor >10
15. Conti, S.; Perali, A.; Hamilton, A. R.; Milošević, M. V.; Peeters, F. M.; Neilson, D. *Chester Supersolid of Spatially Indirect Excitons in Double-Layer Semiconductor Heterostructures*. Phys. Rev. Lett. **2023**, 130 (5), 057001. https://doi.org/10.1103/PhysRevLett.130.057001. Impact Factor 7 to 10 # *
16. Conway, M. A.; Earl, S. K.; Muir, J. B.; Vu, T.-H.-Y.; Tollerud, J. O.; Watanabe, K.; Taniguchi, T.; Fuhrer, M. S.; Edmonds, M. T.; Davis, J. A. *Effects of Floquet Engineering on the Coherent Exciton Dynamics in Monolayer* WS_2. ACS Nano **2023**, 17 (15), 14545–14554. https://doi.org/10.1021/acsnano.3c01318. Impact Factor >10 *
17. Das, K.; Lahiri, S.; Atencia, R. B.; Culcer, D.; Agarwal, A. *Intrinsic Nonlinear Conductivities Induced by the Quantum Metric*. Phys. Rev. B **2023**, 108 (20), L201405. https://doi.org/10.1103/PhysRevB.108.L201405. Impact Factor less than 4
18. De Clercq, D. M.; Yang, J.; Hanif, M.; Alves, J.; Feng, J.; Nielsen, M. P.; Kalantar-Zadeh, K.; Schmidt, T. W. *Exciton Dissociation, Charge Transfer, and Exciton Trapping at the* MoS_2 */ Organic Semiconductor Interface*. J. Phys. Chem. C **2023**, 127 (23), 11260–11267. https://doi.org/10.1021/acs.jpcc.3c01682. Impact Factor 4 to 7
19. Di Bernardo, I.; Ripoll-Sau, J.; Silva-Guillén, J. A.; Calleja, F.; Ayani, C. G.; Miranda, R.; Canadell, E.; Garnica, M.; Vázquez De Parga, A. L. *Metastable Polymorphic Phases in Monolayer* $TaTe_2$. Small **2023**, 19 (29), 2300262. https://doi.org/10.1002/smll.202300262. Impact Factor >10 *

20. Efimkin, D. K.; Syzranov, S. *Weyl Excitations via Helicon-Phonon Mixing in Conducting Materials*. Phys. Rev. B **2023**, 108 (16), L161411. https://doi.org/10.1103/PhysRevB.108.L161411. Impact Factor less than 4 *

21. Eo, Y. S.; Avers, K.; Horn, J. A.; Yoon, H.; Saha, S. R.; Suarez, A.; Fuhrer, M. S.; Paglione, J. *Extraordinary Bulk-Insulating Behavior in the Strongly Correlated Materials FeSi and $FeSb_2$*. Applied Physics Letters **2023**, 122 (23), 233102. https://doi.org/10.1063/5.0148249. Impact Factor less than 4 #

22. Fang, Y.; Philippopoulos, P.; Culcer, D.; Coish, W. A.; Chesi, S. *Recent Advances in Hole-Spin Qubits*. Mater. Quantum. Technol. **2023**, 3 (1), 012003. https://doi.org/10.1088/2633-4356/acb87e. Impact Factor less than 4

23. Farokhnezhad, M.; Coish, W. A.; Asgari, R.; Culcer, D. *Quadrupolar Photovoltaic Effect in the Terahertz Range in a Two-Dimensional Spin-$^3/_2$ Hole System*. Phys. Rev. B **2023**, 107 (8), 085405. https://doi.org/10.1103/PhysRevB.107.085405. Impact Factor less than 4

24. Gholizadeh, S.; Cullen, J. H.; Culcer, D. *Nonlinear Hall Effect of Magnetized Two-Dimensional Spin-$^3/_2$ Heavy Holes*. Phys. Rev. B 2023, 107 (4), L041301. https://journals.aps.org/prb/abstract/10.1103/PhysRevB.107.L041301. Impact Factor less than 4

25. Goodman, N.; Mulkerin, B. C.; Levinsen, J.; Parish, M. M. *Quasi-Equilibrium Polariton Condensates in the Non-Linear Regime and Beyond*. SciPost Phys. **2023**, 15 (3), 116. https://doi.org/10.21468/SciPostPhys.15.3.116. Impact Factor 4 to 7 *

26. Govinden, V.; Prokhorenko, S.; Zhang, Q.; Rijal, S.; Nahas, Y.; Bellaiche, L.; Valanoor, N. *Spherical Ferroelectric Solitons*. Nat. Mater. **2023**, 22 (5), 553–561. https://doi.org/10.1038/s41563-023-01527-y. Impact Factor >10 # *

27. Govinden, V.; Rijal, S.; Zhang, Q.; Nahas, Y.; Bellaiche, L.; Valanoor, N.; Prokhorenko, S. *Stability of Ferroelectric Bubble Domains*. Phys. Rev. Materials **2023**, 7 (1), L011401. https://doi.org/10.1103/PhysRevMaterials.7.L011401. Impact Factor less than 4 *

28. Govinden, V.; Tong, P.; Guo, X.; Zhang, Q.; Mantri, S.; Seyfouri, M. M.; Prokhorenko, S.; Nahas, Y.; Wu, Y.; Bellaiche, L.; Sun, T.; Tian, H.; Hong, Z.; Valanoor, N.; Sando, D. *Ferroelectric Solitons Crafted in Epitaxial Bismuth Ferrite Superlattices*. Nat Commun **2023**, 14 (1), 4178. https://doi.org/10.1038/s41467-023-39841-3. Impact Factor >10 # *

29. Guo, L.; Zhao, W.; Li, Q.; Xu, M.; Chen, L.; Bake, A.; Vu, T.-H.-Y.; He, Y.; Fang, Y.; Cortie, D.; Mo, S.-K.; Edmonds, M. T.; Wang, X.; Dong, S.; Karel, J.; Zheng, R.-K. *Antiferromagnetic Topological Insulating State in $Tb_{0.02}Bi_{1.08}Sb_{0.9}Te_2S$ Single Crystals*. Phys. Rev. B **2023**, 107 (12), 125125. https://doi.org/10.1103/PhysRevB.107.125125. Impact Factor less than 4 # *

30. Han, M.-G.; Camino, F.; Vorobyev, P. A.; Garlow, J.; Rov, R.; Söhnel, T.; Seidel, J.; Mostovoy, M.; Tretiakov, O. A.; Zhu, Y. *Hysteretic Responses of Skyrmion Lattices to Electric Fields in Magnetoelectric Cu_2OSeO_3*. Nano Lett. **2023**, 23 (15), 7143–7149. https://doi.org/10.1021/acs.nanolett.3c02034. Impact Factor >10

31. He, Y.; You, J.; Dickey, M. D.; Wang, X. *Controllable Flow and Manipulation of Liquid Metals*. Adv Funct Materials **2023**, 2309614. https://doi.org/10.1002/adfm.202309614. Impact Factor >10

32. Hossain, M. M.; Shabbir, B.; Liu, J.; Wan, Z.; Walia, S.; Bao, Q.; Alan, T.; Mokkapati, S. *Bisphenol A Detection Using Molybdenum Disulfide (MoS_2) Field-Effect Transistor Functionalized with DNA Aptamers*. Adv Materials Technologies **2023**, 2201793. https://doi.org/10.1002/admt.202201793. Impact Factor 7 to 10 *

33. Hu, Y.-M. R.; Ostrovskaya, E. A.; Estrecho, E. *Wave-Packet Dynamics in a Non-Hermitian Exciton-Polariton System*. Phys. Rev. B **2023**, 108 (11), 115404. https://doi.org/10.1103/PhysRevB.108.115404. Impact Factor less than 4

34. Hu, Y.; Ma, Q.; Zhang, B. Y.; Ren, G.; Ou, R.; Xu, K.; Salek, A.; Yang, Y.; Wen, X.; Li, Q.; Ha, N.; Trinh, V.; Ou, J. Z. *Complex Refractive Index Extraction for Ultrathin Molybdenum Oxides Using Micro-Photonic Integrated Circuit Chips*. Advanced Optical Materials **2023**, 2300340. https://doi.org/10.1002/adom.202300340. Impact Factor >10 *

35. Huang, D.; Sampson, K.; Ni, Y.; Liu, Z.; Liang, D.; Watanabe, K.; Taniguchi, T.; Li, H.; Martin, E.; Levinsen, J.; Parish, M. M.; Tutuc, E.; Efimkin, D. K.; Li, X. *Quantum Dynamics of Attractive and Repulsive Polarons in a Doped $MoSe_2$ Monolayer*. Phys. Rev. X **2023**, 13 (1), 011029. https://doi.org/10.1103/PhysRevX.13.011029. Impact Factor >10 *

36. Katzmarek, D. A.; Mancini, A.; Maier, S. A.; Iacopi, F. *Direct Synthesis of Nanopatterned Epitaxial Graphene on Silicon Carbide*. Nanotechnology **2023**, 34 (40), 405302. https://doi.org/10.1088/1361-6528/ace369. Impact Factor less than 4 *

37. Keser, A. C.; Sushkov, O. *Magnetic Response of a Two-Dimensional Viscous Electron Fluid*. Turkish Journal of Physics **2023**, 47 (1), 28–39. https://doi.org/10.55730/1300-0101.2736. Impact Factor less than 4

38. Kim, D.; Yun, J. S.; Sagotra, A.; Mattoni, A.; Sharma, P.; Kim, J.; Lee, D. S.; Lim, S.; O'Reilly, P.; Brinkman, L.; Green, M. A.; Huang, S.; Ho-Baillie, A.; Cazorla, C.; Seidel, J. *Charge Carrier Transport Properties of Twin Domains in Halide Perovskites*. J. Mater. Chem. A **2023**, 11 (31), 16743–16754. https://doi.org/10.1039/D3TA02565A. Impact Factor >10 *

39. Krix, Z. E.; Sushkov, O. P. *Patterned Bilayer Graphene as a Tunable Strongly Correlated System*. Phys. Rev. B **2023**, 107 (16), 165158. https://doi.org/10.1103/PhysRevB.107.165158. Impact Factor less than 4

40. Kumar, D.; Hellerstedt, J.; Lowe, B.; Schiffrin, A. *Mesoscopic 2D Molecular Self-Assembly on an Insulator*. Nanotechnology **2023**. https://doi.org/10.1088/1361-6528/acba20. Impact Factor less than 4

41. Kumar, S. S.; Mulkerin, B. C.; Parish, M. M.; Levinsen, J. *Trion Resonance in Polariton-Electron Scattering*. Phys. Rev. B **2023**, 108 (12), 125416. https://doi.org/10.1103/PhysRevB.108.125416. Impact Factor less than 4 *

42. Li, G.; Efimkin, D. K. *Equatorial Waves in Rotating Bubble-Trapped Superfluids*. Phys. Rev. A **2023**, 107 (2), 023319. https://doi.org/10.1103/PhysRevA.107.023319. Impact Factor less than 4 *

43. Li, Y.; Chen, Z.; Wang, J.; Li, T.; Tian, M.; Karel, J.; Suzuki, K. *Abnormal Thickness-Dependent Magneto-Transport Properties of vdW Magnetic Semiconductor $Cr_2Si_2Te_6$*. npj 2D Mater Appl **2023**, 7 (1), 39. https://doi.org/10.1038/s41699-023-00404-1. Impact Factor >10 #

44. Liu, H.; Atencia, R. B.; Medhekar, N.; Culcer, D. *Coherent Backscattering in the Topological Hall Effect*. Mater. Quantum. Technol. **2023**, 3 (2), 025002. https://doi.org/10.1088/2633-4356/accac3. Impact Factor less than 4

45. Liu, H.; Cullen, J. H.; Culcer, D. *Topological Nature of the Proper Spin Current and the Spin-Hall Torque*. Phys. Rev. B **2023**, 108 (19), 195434. https://doi.org/10.1103/PhysRevB.108.195434. Impact Factor less than 4

46. Lu, E.; Stuart, A. R.; Chalifour, A. R.; Davidson, J. C.; Keatley, P. S.; Buchanan, K. S.; Livesey, K. L. *Analytic Theory for Néel Skyrmion Size, Accounting for Finite Film Thickness*. Journal of Magnetism and Magnetic Materials **2023**, 584, 171044. https://doi.org/10.1016/j.jmmm.2023.171044. Impact Factor less than 4 *

47. Lv, J.; Wu, Y.; Liu, J.; Gong, Y.; Si, G.; Hu, G.; Zhang, Q.; Zhang, Y.; Tang, J.-X.; Fuhrer, M. S.; Chen, H.; Maier, S. A.; Qiu, C.-W.; Ou, Q. *Hyperbolic Polaritonic Crystals with Configurable Low-Symmetry Bloch Modes*. Nat Commun **2023**, 14 (1), 3894. https://doi.org/10.1038/s41467-023-39543-w. Impact Factor >10 *

48. Mallett, B.; Zhang, Y.; Pot, C.; Van Koughnet, K.; Stanley, B.; Buckley, R. G.; Koo, A.; Yin, Y.; Medhekar, N. V.; Granville, S. *Using Optical Spectroscopy to Probe the Impact of Atomic Disorder on the Heusler Alloy Co_2 MnGa*. Phys. Rev. Materials **2023**, 7 (9), 094203. https://doi.org/10.1103/PhysRevMaterials.7.094203. Impact Factor less than 4 #

49. Mazumder, A.; Nguyen, C. K.; Aung, T.; Low, M. X.; Rahman, Md. A.; Russo, S. P.; Tawfik, S. A.; Wang, S.; Bullock, J.; Krishnamurthi, V.; Syed, N.; Ranjan, A.; Zavabeti, A.; Abidi, I. H.; Guo, X.; Li, Y.; Ahmed, T.; Daeneke, T.; Al-Hourani, A.; Balendhran, S.; Walia, S. *Long Duration Persistent Photocurrent in 3 nm Thin Doped Indium Oxide for Integrated Light Sensing and In-Sensor Neuromorphic Computation*. Adv Funct Materials **2023**, 2303641. https://doi.org/10.1002/adfm.202303641. Impact Factor >10 *

50. Mousavi, M.; Ghasemian, M. B.; Baharfar, M.; Tajik, M.; Chi, Y.; Mao, G.; Kalantar-Zadeh, K.; Tang, J. *Liquid Metal Interface for Two-Precursor Autogenous Deposition of Metal Telluride–Tellurium Networks*. ACS Appl. Mater. Interfaces **2023**, 15 (40), 47394–47404. https://doi.org/10.1021/acsami.3c10049. Impact Factor 7 to 10 *

51. Mulkerin, B. C.; Tiene, A.; Marchetti, F. M.; Parish, M. M.; Levinsen, J. *Exact Quantum Virial Expansion for the Optical Response of Doped Two-Dimensional Semiconductors*. Phys. Rev. Lett. **2023**, 131 (10), 106901. https://doi.org/10.1103/PhysRevLett.131.106901. Impact Factor 7 to 10 *

52. Nadeem, M.; Fuhrer, M. S.; Wang, X. *The Superconducting Diode Effect*. Nat Rev Phys **2023**, 5 (10), 558–577. https://doi.org/10.1038/s42254-023-00632-w. Impact Factor >10

53. Nguyen, A.; Akhgar, G.; Cortie, D. L.; Bake, A.; Pastuovic, Z.; Zhao, W.; Liu, C.; Chen, Y.-H.; Suzuki, K.; Fuhrer, M. S.; Culcer, D.; Hamilton, A. R.; Edmonds, M. T.; Karel, J. *Increased Phase Coherence Length in a Porous Topological Insulator*. Phys. Rev. Materials **2023**, 7 (6), 064202. https://doi.org/10.1103/PhysRevMaterials.7.064202. Impact Factor less than 4 # *

54. Nguyen, C. K.; Mazumder, A.; Mayes, E. L.; Krishnamurthi, V.; Zavabeti, A.; Murdoch, B. J.; Guo, X.; Aukarasereenont, P.; Dubey, A.; Jannat, A.; Wei, X.; Truong, V. K.; Bao, L.; Roberts, A.; McConville, C. F.; Walia, S.; Syed, N.; Daeneke, T. *2-nm-Thick Indium Oxide Featuring High Mobility*. Adv Materials Inter **2023**, 2202036. https://doi.org/10.1002/admi.202202036. Impact Factor 4 to 7 *

55. Nguyen, C. T.; Schoenherr, P.; Seidel, J. *Intrinsic Mechanical Compliance of 90° Domain Walls in $PbTiO_3$*. Adv Funct Materials **2023**, 2211906. https://doi.org/10.1002/adfm.202211906. Impact Factor >10

56. Nguyen, C.-P. T.; Schoenherr, P.; Salje, E. K. H.; Seidel, J. *Crackling Noise Microscopy*. Nat Commun **2023**, 14 (1), 4963. https://doi.org/10.1038/s41467-023-40665-4. Impact Factor >10

57. Parker, C. J.; Krishnamurthi, V.; Zuraiqi, K.; Nguyen, C. K.; Irfan, M.; Jabbar, F.; Yang, D.; Aukarasereenont, M. P.; Mayes, E. L. H.; Murdoch, B. J.; Elbourne, A.; Chiang, K.; Daeneke, T. *Synthesis of Planet-Like Liquid Metal Nanodroplets with Promising Properties for Catalysis*. Adv Funct Materials 2023, 2304248. https://doi.org/10.1002/adfm.202304248. Impact Factor >10

58. Pradeepkumar, A.; Cheng, H. H.; Liu, K. Y.; Gebert, M.; Bhattacharyya, S.; Fuhrer, M. S.; Iacopi, F. *Low-Leakage Epitaxial Graphene Field-Effect Transistors on Cubic Silicon Carbide on Silicon*. Journal of Applied Physics **2023**, 133 (17), 174503. https://doi.org/10.1063/5.0147376. Impact Factor less than 4 *

59. Reeves, M.; Davis, M. *Bistability and Nonequilibrium Condensation in a Driven-Dissipative Josephson Array: A c-Field Model*. SciPost Phys. **2023**, 15 (2), 068. https://doi.org/10.21468/SciPostPhys.15.2.068. Impact Factor 4 to 7

60. Rendell, M. J.; Liles, S. D.; Srinivasan, A.; Klochan, O.; Farrer, I.; Ritchie, D. A.; Hamilton, A. R. *Spin Polarization and Spin-Dependent Scattering of Holes Observed in Transverse Magnetic Focusing*. Phys. Rev. B **2023**, 107 (4), 045304. https://doi.org/10.1103/PhysRevB.107.045304. Impact Factor 4 to 7

61. Sarkar, A.; Wang, Z.; Rendell, M.; Hendrickx, N. W.; Veldhorst, M.; Scappucci, G.; Khalifa, M.; Salfi, J.; Saraiva, A.; Dzurak, A. S.; Hamilton, A. R.; Culcer, D. *Electrical Operation of Planar Ge Hole Spin Qubits in an In-Plane Magnetic Field*. Phys. Rev. B **2023**, 108 (24), 245301. https://doi.org/10.1103/PhysRevB.108.245301. Impact Factor less than 4

62. Scammell, H. D.; Ingham, J.; Li, T.; Sushkov, O. P. *Chiral Excitonic Order from Twofold van Hove Singularities in Kagome Metals*. Nat Commun **2023**, 14 (1), 605. https://doi.org/10.1038/s41467-023-35987-2. Impact Factor >10

63. Scammell, H. D.; Scheurer, M. S. *Tunable Superconductivity and Möbius Fermi Surfaces in an Inversion-Symmetric Twisted van Der Waals Heterostructure*. Phys. Rev. Lett. **2023**, 130 (6), 066001. https://doi.org/10.1103/PhysRevLett.130.066001. Impact Factor 7 to 10

64. Scammell, H. D.; Sushkov, O. P. *Dynamical Screening and Excitonic Bound States in Biased Bilayer Graphene*. Phys. Rev. B **2023**, 107 (8), 085104. https://doi.org/10.1103/PhysRevB.107.085104. Impact Factor less than 4

65. Scammell, H. D.; Sushkov, O. P. *Exciton Condensation in Biased Bilayer Graphene*. Phys. Rev. Research **2023**, 5 (4), 043176. https://doi.org/10.1103/PhysRevResearch.5.043176. Impact Factor 4 to 7

66. Sharma, P.; Seidel, J. *Neuromorphic Functionality of Ferroelectric Domain Walls*. Neuromorph. Comput. Eng. **2023**, 3 (2), 022001. https://doi.org/10.1088/2634-4386/accfbb. Impact Factor less than 4 *

67. Singh, M.; Ingle, A.; González, A.; Mariathomas, P.; Ramanathan, R.; Taylor, P. D.; Christofferson, A. J.; Spencer, M. J. S.; Low, M. X.; Ahmed, T.; Walia, S.; Trasobares, S.; Manzorro, R.; Calvino, J. J.; García-Fernández, E.; Orte, A.; Dominguez-Vera, J. M.; Bansal, V. *Repairing and Preventing Photooxidation of Few-Layer Black Phosphorus with β-Carotene*. ACS Nano **2023**, 17 (9), 8083–8097. https://doi.org/10.1021/acsnano.2c10232. Impact Factor >10 *

68. Sortino, L.; Gülmüs, M.; Tilmann, B.; De S. Menezes, L.; Maier, S. A. *Radiative Suppression of Exciton–Exciton Annihilation in a Two-Dimensional Semiconductor*. Light Sci Appl **2023**, 12 (1), 202. https://doi.org/10.1038/s41377-023-01249-5. Impact Factor >10 *

69. Su, R.; Zhang, J.; Wong, V.; Zhang, D.; Yang, Y.; Luo, Z.; Wang, X.; Wen, H.; Liu, Y.; Seidel, J.; Yang, X.; Pan, Y.; Li, F. *Engineering Sub-Nanometer Hafnia-Based Ferroelectric to Break The Scaling Relation for High-Efficiency Piezocatalytic Water Splitting*. Advanced Materials **2023**, 2303018. https://doi.org/10.1002/adma.202303018. Impact Factor >10

70. Sushkov, A. O.; Sushkov, O. P.; Yaresko, A. *Effective Electric Field: Quantifying the Sensitivity of Searches for New P, T-Odd Physics with $EuCl_3 \cdot 6H_2O$. Phys*. Rev. A 2023, 107 (6), 062823. https://doi.org/10.1103/PhysRevA.107.062823. Impact Factor less than 4

71. Tan, C.; Liao, J.-H.; Zheng, G.; Algarni, M.; Lin, J.-Y.; Ma, X.; Mayes, E. L. H.; Field, M. R.; Albarakati, S.; Panahandeh-Fard, M.; Alzahrani, S.; Wang, G.; Yang, Y.; Culcer, D.; Partridge, J.; Tian, M.; Xiang, B.; Zhao, Y.-J.; Wang, L. *Room-Temperature Magnetic Phase Transition in an Electrically Tuned van Der Waals Ferromagnet*. Phys. Rev. Lett. **2023**, 131 (16), 166703. https://doi.org/10.1103/PhysRevLett.131.166703. Impact Factor 7 to 10 #

72. Tang, L.; Mao, Z.; Wang, C.; Fu, Q.; Wang, C.; Zhang, Y.; Shen, J.; Yin, Y.; Shen, B.; Tan, D.; Li, Q.; Wang, Y.; Medhekar, N. V.; Wu, J.; Yuan, H.; Li, Y.; Fuhrer, M. S.; Zheng, C. *Giant Piezoresistivity in a van Der Waals Material Induced by Intralayer Atomic Motions*. Nat Commun **2023**, 14 (1), 1519. https://doi.org/10.1038/s41467-023-37239-9. Impact Factor >10 #

73. Tiene, A.; Mulkerin, B. C.; Levinsen, J.; Parish, M. M.; Marchetti, F. M. *Crossover from Exciton Polarons to Trions in Doped Two-Dimensional Semiconductors at Finite Temperature*. Phys. Rev. B **2023**, 108 (12), 125406. https://doi.org/10.1103/PhysRevB.108.125406. Impact Factor less than 4 *

74. Tilmann, B.; Huq, T.; Possmayer, T.; Dranczewski, J.; Nickel, B.; Zhang, H.; Krivitsky, L.; Kuznetsov, A. I.; De S. Menezes, L.; Vezzoli, S.; Sapienza, R.; Maier, S. A. *Comparison of Harmonic Generation from Crystalline and Amorphous Gallium Phosphide Nanofilms*. Advanced Optical Materials **2023**, 2300269. https://doi.org/10.1002/adom.202300269. Impact Factor >10 *

75. Tkachenko, O. A.; Tkachenko, V. A.; Baksheev, D. G.; Sushkov, O. P. *Effect of Disorder on Magnetotransport in Semiconductor Artificial Graphene*. Jetp Lett. 2023, 117 (3), 222–227. https://doi.org/10.1134/S0021364022603219. Impact Factor less than 4

76. Underwood, A. P. C.; Groszek, A. J.; Yu, X.; Blakie, P. B.; Williamson, L. A. *Berezinskii-Kosterlitz-Thouless Transitions in an Easy-Plane Ferromagnetic Superfluid*. Phys. Rev. Research **2023**, 5 (1), L012045. https://doi.org/10.1103/PhysRevResearch.5.L012045. Impact Factor 4 to 7

77. Wang, D. Q.; Krix, Z.; Sushkov, O. P.; Farrer, I.; Ritchie, D. A.; Hamilton, A. R.; Klochan, O. *Formation of Artificial Fermi Surfaces with a Triangular Superlattice on a Conventional Two-Dimensional Electron Gas*. Nano Lett. **2023**, 23 (5), 1705–1710. https://doi.org/10.1021/acs.nanolett.2c04358. Impact Factor >10

78. Wang, L.; Zhang, D.; Luo, Z.-D.; Sharma, P.; Seidel, J. *Flexoelectric and Electrostatic Effects on Mechanical Properties of $CuInP_2S_6$*. Applied Materials Today **2023**, 35, 101981. https://doi.org/10.1016/j.apmt.2023.101981. Impact Factor 7 to 10

79. Wang, L.; Zhang, D.; Luo, Z.; Sharma, P.; Seidel, J. *Inhomogeneous Friction Behaviour of Nanoscale Phase Separated Layered $CuInP_2S_6$*. Adv Funct Materials **2023**, 2303583. https://doi.org/10.1002/adfm.202303583. Impact Factor >10 *

80. Wang, Q.; Zhao, J.; Wu, W.; Zhou, Y.; Li, Q.; Edmonds, M. T.; Yang, S. A. *Magnetic and Electronic Properties of Bulk and Two-Dimensional $FeBi_2Te_4$: A First-Principles Study*. Chinese Phys. B **2023**, 32 (8), 087506. https://doi.org/10.1088/1674-1056/acd522. Impact Factor less than 4 *

81. Woffinden, C.; Groszek, A. J.; Gauthier, G.; Mommers, B. J.; Bromley, M. W. J.; Haine, S. A.; Rubinsztein-Dunlop, H.; Davis, M. J.; Neely, T. W.; Baker, M. *Viability of Rotation Sensing Using Phonon Interferometry in Bose-Einstein Condensates*. SciPost Phys. **2023**, 15 (4), 128. https://doi.org/10.21468/SciPostPhys.15.4.128. Impact Factor 4 to 7

82. Wurdack, M.; Yun, T.; Katzer, M.; Truscott, A. G.; Knorr, A.; Selig, M.; Ostrovskaya, E. A.; Estrecho, E. *Negative-Mass Exciton Polaritons Induced by Dissipative Light-Matter Coupling in an Atomically Thin Semiconductor*. Nat Commun **2023**, 14 (1), 1026. https://doi.org/10.1038/s41467-023-36618-6. Impact Factor >10 #

83. Wurdack, M.; Yun, T.; Katzer, M.; Truscott, A. G.; Knorr, A.; Selig, M.; Ostrovskaya, E. A.; Estrecho, E. *Publisher Correction: Negative-Mass Exciton Polaritons Induced by Dissipative Light-Matter Coupling in an Atomically Thin Semiconductor*. Nat Commun **2023**, 14 (1), 1193. https://doi.org/10.1038/s41467-023-36962-7. Impact Factor >10 #

84. Xiang, F.; Gupta, A.; Chaves, A.; Krix, Z. E.; Watanabe, K.; Taniguchi, T.; Fuhrer, M. S.; Peeters, F. M.; Neilson, D.; Milošević, M. V.; Hamilton, A. R. *Intra-Zero-Energy Landau Level Crossings in Bilayer Graphene at High Electric Fields*. Nano Lett. **2023**, 23 (21), 9683–9689. https://doi.org/10.1021/acs.nanolett.3c01456. Impact Factor >10 #

85. Xu, M.; Guo, L.; Chen, L.; Zhang, Y.; Li, S.-S.; Zhao, W.; Wang, X.; Dong, S.; Zheng, R.-K. *Emerging Weak Antilocalization Effect in $Ta_{0.7}Nb_{0.3}Sb_2$ Semimetal Single Crystals*. Front. Phys. **2023**, 18 (1), 13304. https://doi.org/10.1007/s11467-022-1198-6. Impact Factor less than 4

86. Yang, G.; Sang, L.; Zhang, C.; Ye, N.; Hamilton, A.; Fuhrer, M. S.; Wang, X. *The Role of Spin in Thermoelectricity*. Nat Rev Phys **2023**, 5 (8), 466–482. https://doi.org/10.1038/s42254-023-00604-0. Impact Factor >10

87. Yin, Y.; Wang, C.; Fuhrer, M. S.; Medhekar, N. V. *Extracting Unconventional Spin Texture in Two Dimensional Topological Crystalline Insulator Bismuthene via Tuning Bulk-Edge Interactions*. Materials Today Physics **2023**, 36, 101168. https://doi.org/10.1016/j.mtphys.2023.101168. Impact Factor >10

88. You, J.; Shao, J.; He, Y.; Guo, X.; See, K. W.; Wang, Z. L.; Wang, X. *Simulation Model of a Non-contact Triboelectric Nanogenerator Based on Electrostatic Induction*. EcoMat **2023**, e12392. https://doi.org/10.1002/eom2.12392. Impact Factor >10 #

89. Yu, R.; Han, J.; Chi, Y.; Zheng, J.; Fuchs, R.; Ghasemian, M. B.; Rahim, Md. A.; Tang, S.; Mao, G.; Kalantar-Zadeh, K.; Tang, J. *Impact of Minor Alloy Components on the Electrocapillarity and Electrochemistry of Liquid Metal Fractals*. Adv Funct Materials **2023**, 2301348. https://doi.org/10.1002/adfm.202301348. Impact Factor >10 *

90. Zhang, D.; Wang, L.; Li, L.; Sharma, P.; Seidel, J. *Varied Domain Structures in 0.7Pb $(Mg_{1/3}Nb_{2/3})O_3$-0.0_3 Single Crystals.* Microstructures **2023**, 3 (4). https://doi.org/10.20517/microstructures.2023.57. Impact Factor less than 4 *

91. Zhang, H.; Alanthattil, A.; Webster, R. F.; Zhang, D.; Ghasemian, M. B.; Venkataramana, R. B.; Seidel, J.; Sharma, P. *Robust Switchable Polarization and Coupled Electronic Characteristics of Magnesium-Doped Zinc Oxide*. ACS Nano **2023**, 17 (17), 17148–17157. https://doi.org/10.1021/acsnano.3c04937. Impact Factor >10

92. Zhang, S.-J.; Chen, L.; Li, S.-S.; Zhang, Y.; Yan, J.-M.; Tang, F.; Fang, Y.; Fei, L.-F.; Zhao, W.; Karel, J.; Chai, Y.; Zheng, R.-K. *Coexistence of Logarithmic and SdH Quantum Oscillations in Ferromagnetic Cr-Doped Tellurium Single Crystals*. J. Phys.: Condens. Matter **2023**, 35 (24), 245701. https://doi.org/10.1088/1361-648X/acc5ca. Impact Factor less than 4

93. Zheng, G.; Tan, C.; Chen, Z.; Wang, M.; Zhu, X.; Albarakati, S.; Algarni, M.; Partridge, J.; Farrar, L.; Zhou, J.; Ning, W.; Tian, M.; Fuhrer, M. S.; Wang, L. *Electrically Controlled Superconductor-to-Failed Insulator Transition and Giant Anomalous Hall Effect in Kagome Metal CsV_3Sb_5 Nanoflakes*. Nat Commun **2023**, 14 (1), 678. https://doi.org/10.1038/s41467-023-36208-6. Impact Factor >10 #

94. Zheng, J.; Sharma, A.; Kumeria, T.; Chi, Y.; Ghasemian, M. B.; Mao, G.; Tang, J.; Kumar, P.; Rahim, Md. A.; Kalanta-Zadeh, K. *Dynamic Zinc in Liquid Metal Media as a Metal Ion Source for Highly Porous ZIF-8 Synthesis*. Adv Funct Materials **2023**, 2300969. https://doi.org/10.1002/adfm.202300969. Impact Factor >10 *

95. Zhou, J.; Sando, D.; Summers, M.; Jia, Y.; Wang, K.; Valanoor, N.; Zhang, Q. *Gelation Chemistry and Phase Development of Chemical Solution Deposition-Derived Sm-Doped $BiFeO_3$ Thin Films: The Role of Sm Dopant*. ACS Appl. Electron. Mater. **2023**, acsaelm.3c00007. https://doi.org/10.1021/acsaelm.3c00007. Impact Factor >10

DOI **Article Digital object identifier**
**publications involving partner investigators**
***** **publications involving associate investigators**
Impact factor at time of publication

Awards, honours and grants

MEMBERS INVOLVED	NAME OF AWARD GRANT SCHEME	DESCRIPTION OF AWARD / GRANT	FUNDING SOURCE	GRANT ID	TOTAL AMOUNT OF FUNDING (AUD)
Mitko Oldfield	Monash University 3 Minute Thesis Competition	Runner Up 2023	Monash University		
Alex Hamilton	ARC LIEF	Cryogenic microwave characterization facility for quantum technologies. This facility will lead to a significant improvement in research efficiency, allowing for rapid optimization of devices and components prior to integration into a larger quantum system. Expected outcomes include the creation of new intellectual property, enhanced engagement with industry, and will further boost Australia's efforts to build a commercially scalable quantum computer.	Other ARC grants	LE240100045	410,000
Alex Hamilton	ARC Industry Laureate Fellowship	Unleashing the combined power of electrons and holes for quantum computing. This Fellowship will partner with Diraq, a world-leading Australian company developing a revolutionary new silicon quantum computing technology, to solve key issues in the race to scale from small scale prototypes to industrially relevant quantum computers. It will integrate electrons and holes, semiconducting and superconducting functionalities, into a single platform, link with industrial partners, and reinforce Australia's leadership position in quantum computing technologies.	Other ARC grants	IL230100072	3,759,824
Alex Hamilton, Jan Seidel, Julie Karel, Torben Daeneke, Yuerui (Larry) Lu	ARC LIEF	Quantum microscopy facility for ultrasensitive nanoscale magnetic imaging. The new quantum microscopy facility will enable state-of-the-art capabilities in mapping chemical, magnetic, optical, electronic, and spectral properties, providing cutting-edge tools that will enable breakthroughs in both existing and future multi-disciplinary projects in photonics, quantum devices, nanomaterials, nanoelectronics, biotechnology, and energy technology as key drivers of the new economy in Australia.	Other ARC grants	LE240100092	1,100,000
Catherine Stampfl	ARC Laureate Fellowship	2023 Georgina Sweet Australian Laureate Fellowship: Computational design of frontier materials for sustainable technologies	Other ARC grants	FL230100176	2,920,000

MEMBERS INVOLVED	NAME OF AWARD GRANT SCHEME	DESCRIPTION OF AWARD / GRANT	FUNDING SOURCE	GRANT ID	TOTAL AMOUNT OF FUNDING (AUD)
Dimi Culcer, Allan MacDonald	ARC Discovery Project	Topological semiconductors resonate with an elusive form of radiation. The project expects to provide this understanding of great significance and generate new knowledge in physics and materials science. Expected outcomes include a results database that will guide experiments and enable future sensor design. The project expects to provide substantial benefits by identifying the best materials for use as sensors in this frequency range, which has applications in communications, defence, and in the Science and Research Priorities of Food and Transport.	Other ARC grants	DP240101062	467,327
Emma Laird	ARC Discovery Project	Hydrodynamics of quantum fluids. This project intends to fill in this knowledge gap by developing new hydrodynamic theories of quantum fluids formed by ultracold quantum gases. The expected outcomes are the knowledge and theoretical tools required to underpin Australia, advances in quantum technology applications, such as the design of quantum heat engines, control of heat transport in quantum nanowires, and fabrication of new energy-efficient materials.	Other ARC grants	DP240101033	304,031
Jan Seidel, Pankaj Sharma	ARC Discovery Project	Engineered topological nanostructures - a new frontier in materials design. The project's expected outcomes are new concepts for the synthesis and design of topological nanostructures for such applications. The utilization of these materials will benefit efficient controllable functionality for future nanoelectronics.	Other ARC grants	DP240100238	600,044
Kourosh Kalantar-zadeh, Francois-Marie Allioux	ARC Discovery Project	Liquid metal solvents for high entropy and atomically configured systems. Molecular imprinting, mechanical and electrochemical triggers will control interfacial atomic organisation and precipitation. The growth mechanisms, both at the interface and in the bulk, will be explored by high energy probing techniques and computational simulations. We will offer new metallurgical paradigms for future catalysis and sensing concepts.	Other ARC grants	DP240101086	587,000

MEMBERS INVOLVED	NAME OF AWARD GRANT SCHEME	DESCRIPTION OF AWARD / GRANT	FUNDING SOURCE	GRANT ID	TOTAL AMOUNT OF FUNDING (AUD)
Kristian Helmerson	ARC LIEF	National Electron Beam Irradiation Facility. This project expects to generate new knowledge and manufacturing capacity in the areas of quantum sensing and quantum computing by enriching doped diamond and other wide band gap materials via controlled electron irradiation techniques. Expected outcomes include the creation of new quantum engineered materials and devices via an academic and industry collaborative effort. The proposed facility should provide significant benefits to Australian researchers and quantum start-ups through unrestricted access to a sovereign facility entirely dedicated to their needs, aiding training of the future quantum workforce.	Other ARC grants	LE240100019	740,000
Michelle Spencer, Torben Daeneke	ARC Discovery Project	Liquid Metal Interfaces - A Novel Platform for Catalysis. The project expects to generate new knowledge in understanding the reaction dynamics occurring at the gas-liquid metal interface under true working conditions and the composition-catalytic activity relationships of multi-component liquid alloy catalysts through a combined experimental and computational/theoretical approach. The expected outcomes are new liquid metal alloys that open the gateway to a new dimension of catalytic applications. The project should benefit Australia - key societal challenges of emissions reduction, hydrogen storage and food security.	Other ARC grants	DP240101215	456,742
Pankaj Sharma	ARC LIEF	State-of-the-art atomic force microscopy facilities for South Australia. The facility will provide unparalleled capabilities not currently available in Australia and will catapult knowledge in multiple fields, from critical minerals and clean energy to mechanobiology. Expected outcomes include more efficient and eco-friendly resource recovery and energy production, future foods and cures, and advanced (bio)materials. The project will strengthen and amplify Australia, capacity and global leadership to translate fundamental nano-scale phenomena and properties into innovative materials, technologies, and processes.	Other ARC grants	LE240100129	530,721

AWARDS, HONOURS AND GRANTS

MEMBERS INVOLVED	NAME OF AWARD GRANT SCHEME	DESCRIPTION OF AWARD / GRANT	FUNDING SOURCE	GRANT ID	TOTAL AMOUNT OF FUNDING (AUD)
Pankaj Sharma	ARC Discovery Project	Programmable Ferroelectric Nanoelectronics for In-memory Computing. Expected outcomes include new memory design, material principles and ferroelectric devices capable of not only storing huge amounts of data but also instant fast processing and brain like learning. Project benefits include high performance hardware solutions for Artificial Intelligence and Big data boosting Australian quantum technology and industries.	Other ARC grants	DP240102137	373,732
Sumeet Walia	ARC Discovery Project	Bioinspired photoreceptor and smart neural mimicking technologies. This is expected to generate new fundamental and applied knowledge in bioengineered optoelectronic systems. Expected outcomes of the project include new materials with tailored properties at an atomic level for dynamic control of current under different light stimulus wavelengths. This should provide significant benefits such as new advanced materials driven smart architectures that overcome limitations of solid-state systems for next generation of smart technologies.	Other ARC grants	DP240100145	451,143
Abhay Gupta	Best Poster Award	One of the three Best Poster Award at the Summer School on 2D Quantum Matter in Lucca, Italy.	Other external funding		420
Ferenc Krausz	2023 Nobel prize for physics	Prof Ferenc Krausz (MPQ) was a co-recipient of the 2023 Nobel Prize in Physics for his work in attosecond physics.	Other external funding		
Matthew Davis, Andrew Groszek	Army Quantum Challenge 2023	Funding to participate in Army's Quantum Challenge 2023, from May-August.	Other external funding		60,000
Michael Fuhrer	Fellow of the Australian Academy of Science	Fellows of the Australian Academy of Science are among the nation's most distinguished scientists, elected by their peers for ground-breaking research and contributions that have had clear impact			
Oliver Paull	AINSE Gold Medal	AINSE Scholar Gold Medal recognises excellence and impact in research and is a highly competitive award - only one is awarded per year.			

MEMBERS INVOLVED	NAME OF AWARD GRANT SCHEME	DESCRIPTION OF AWARD / GRANT	FUNDING SOURCE	GRANT ID	TOTAL AMOUNT OF FUNDING (AUD)
Yuefeng Yin	NCI Adapter Scheme	"Project title: Exploring new approaches of modeling defects in materials. Awarded 250 KSU computational time to be used in NCI Gadi supercomputer."			
Yuerui (Larry) Lu	Malcolm McIntosh Prize for Physical Scientist of the Year	"The Australian National University, Professor Yuerui (Larry) Lu received the 2023 Malcolm McIntosh Prize for Physical Scientist of the Year. He has made a significant contribution to educating and developing the next generation of nanoscience and nanotechnology researchers. Professor Lu was recognised for discovering interlayer exciton pairs, which can help to unravel the phenomenon of superfluidity. This discovery is paving the way for new electronic devices that are more energy-efficient and faster. He also made the world, thinnest micro-lens, only 1/2000th the thickness of a human hair. This can be used to make lightweight optical systems, opening possibilities for space exploration, medical imaging, environmental monitoring and food safety."			
Yuerui (Larry) Lu	2023 Pawsey Medal	Australian Academy of Science Honorific Awards for Prof Lu's work on possibilities of the world's thinnest lens			

PERFORMANCE

Patents

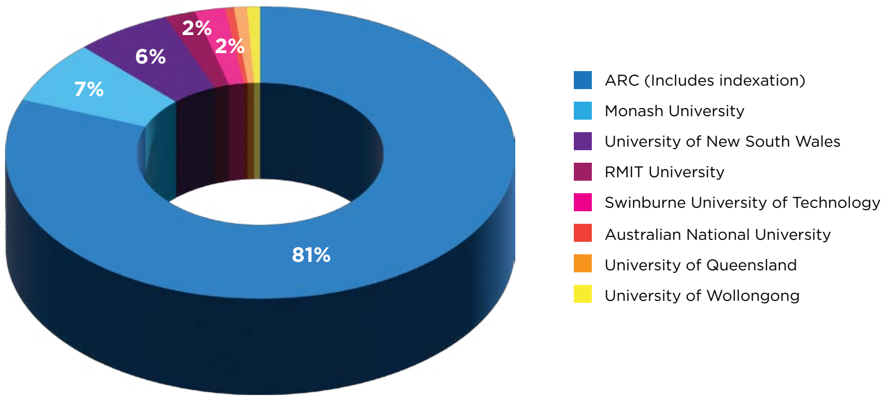
FLEET MEMBERS INVOLVED	PATENT TITLE	PATENT IDENTIFICATION NUMBER	DATE FILED
Torben Daeneke	Method and catalyst for producing ammonia	2022903994	23-12-2022

Centre finance

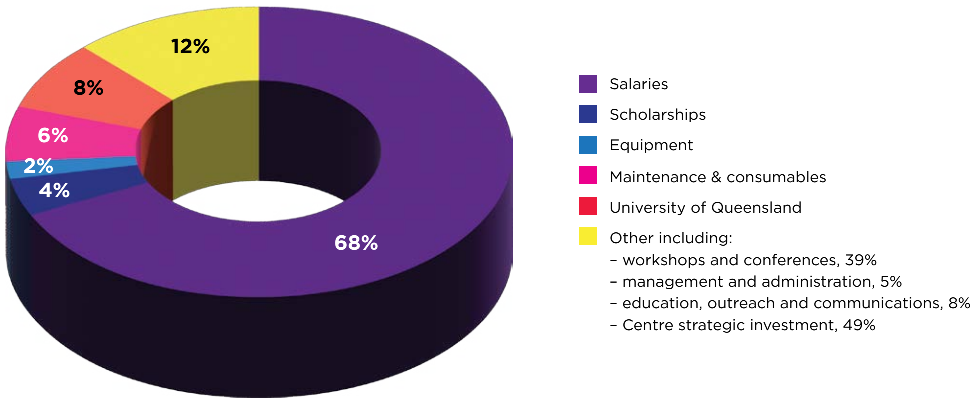
2023-2024 FINANCIAL STATEMENT

REPORTING PERIOD	2023	2024 CURRENT PERIOD
Carry Forward From 2022	**5,715,654**	
INCOME	**2023 ACTUAL ($)**	**2024 FORECAST ($)**
ARC (includes indexation in actual)	5,443,263	-
Monash University	496,000	-
University of New South Wales	404,336	-
RMIT University	155,000	-
Swinburne University of Technology	116,000	-
Australian National University	29,000	-
University of Queensland	58,000	-
University of Wollongong	58,000	-
TOTAL INCOME	**6,759,599**	
EXPENDITURE	**2023 ACTUAL ($)**	**2024 & beyond forecast ($)**
Personnel	5,300,112	4,102,167
- Salaries	4,974,635	3,758,474
- Scholarships	325,477,498	343,693
Equipment	117,835	99,938
Maintenance & consumables	409,906	289,380
Travel and visitor support	577,166	413,119
Other	906,376	259,253
- Workshops and conferences	351,382	-
- Management and administration	42,508	-
- Education, outreach and communications	69,546	-
- Centre strategic investment	442,940	-
TOTAL EXPENDITURE	**7,311,396**	**5,163,857**
CARRIED FORWARD TO 2024	**5,163,857**	

2023 ACTUAL INCOME



2023 ACTUAL EXPENDITURE



COLLABORATING ORGANISATION	2023 ACTUAL ($)
Monash University	1,246,882
University of New South Wales Sydney	1,125,755
RMIT University	417,6904
Swinburne University of Technology	378,073
Australian National University	169,721
University of Queensland	57,061
University of Wollongong	160,946
Australian Nuclear Science and Technology Organisation	1,292,246
Australian Synchrotron	536,26
High Magnetic Field Laboratory, China	10,000
Joint Quantum Insitute, USA	118,048
MacDiarmid Institute - Victoria University of Wellington, New Zealand	18,000
Max Planck Institute of Quantum Optics, Germany	8,625
National University of Singapore, Singapore	73,780
Tsinghua University, China	73,780
Universitat Wurzburg, Germany	19,512
Univerity of Camerino, Italy	28,258
University of Colorado Boulder, USA	17,000
University of Maryland, USA	42,700
University of Texas, USA	18,000
Wroclaw University of Science and Technology, Poland	26,800
TOTAL IN-KIND CONTRIBUTIONS	**5,839,137**

Image credits

ARC CoE network page 68

Australian Academy of Technology and Engineering page 4, 85

Chris McGuigan page 57

David Swift, Australian Museum page 82, 83

Errol Hunt page 73, 74, 75, 81, 96

Grant Turner page 12, 13, 18, 23, 24, 26, 27, 28, 29, 32, 35, 48, 49, 63, 65

Jason Major page 30, 72, 79, 80, 81, 83

Karen Bayros page 5

Kath Tajer page 94

Kyle Boschen page 86, 87

Mark Chew page 10

Melbourne Knowledge Week page 94

Michael Fuhrer page 84, 86, 87, 100

Murray Rix page 47, 88, 89, 92

Pablo Resendiz Vazquez page 79

Phil Dooley page 52, 54

Phillip Hatton page 1, 16, 20, 42, 86, 87, 98, 111

RMIT University page 50

Shane McLean page 78

Simon Milder page 78

Steve Morton page 2, 4, 11, 21, 53, 56, 58, 60, 67, 79

Swinburne University of Technology page 13, 56

Tenille Ibbotson page 86, 87

Women Leaders Institute page 19

FLEET
Landing event,
May 2024

FLEET.org.au/landing

OUR PARTNERS

FLEET is an Australian Research Council Centre of Excellence linking a highly interdisciplinary team of high-profile Australian and international researchers.