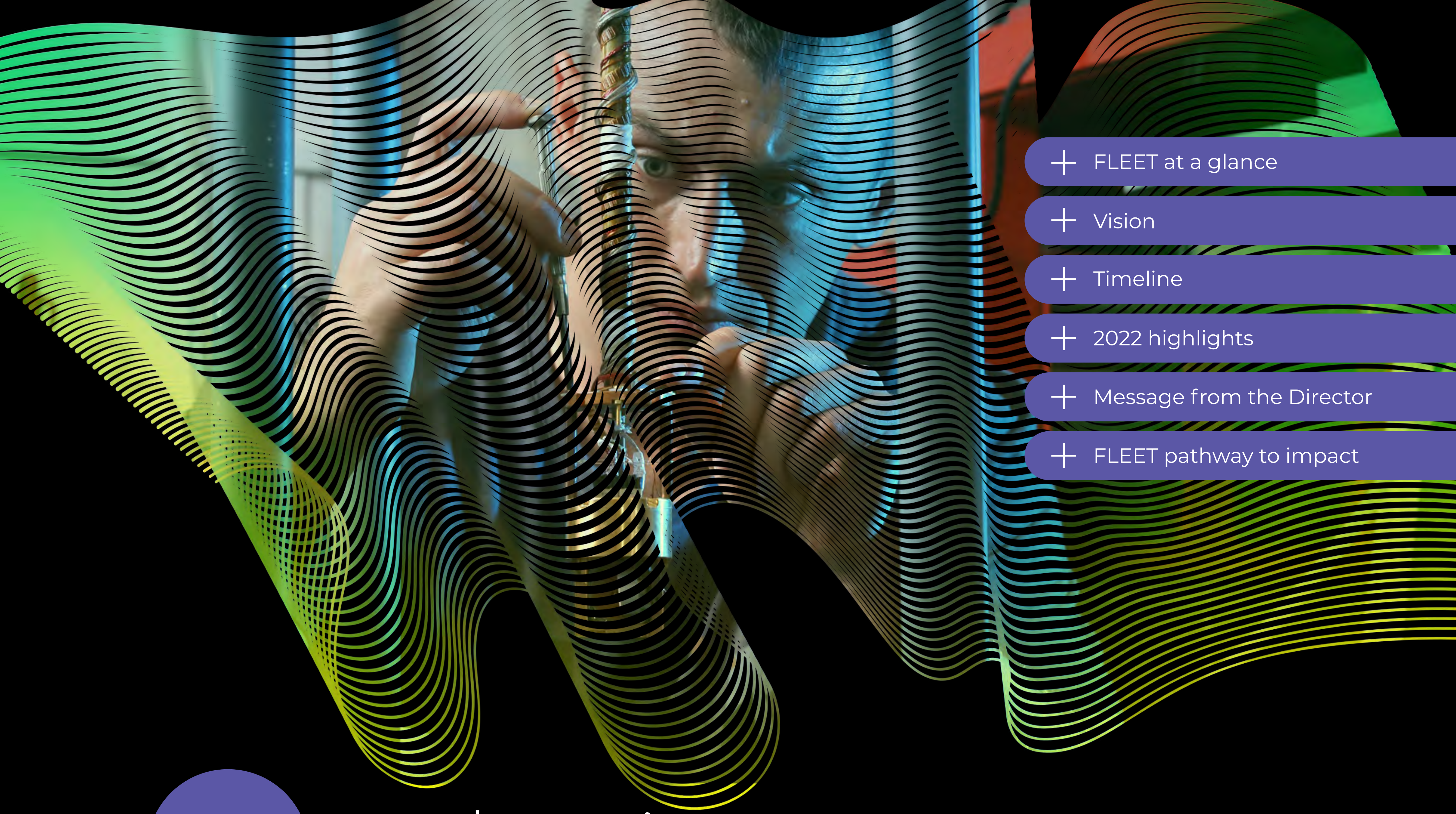
FLEET

ANNUAL REPORT 2022

FLEET

ARC CENTRE OF EXCELLENCE IN
FUTURE LOW-ENERGY
ELECTRONICS TECHNOLOGIES

FLEET operates on the lands of the Wurundjeri and Bunurong people of the Kulin nations (of the Melbourne region), the Gadigal people of the Eora Nation (Sydney), the Dharawal people (Wollongong), the Ngunnawal and Ngambri people (Canberra), and the Turrbal and Yugara people (Brisbane).



Introduction

FLEET at a glance

244
CENTRE MEMBERS AND AFFILIATES

213
INVESTIGATORS AND RESEARCH ASSOCIATES

21
RESEARCH LEADERS FROM 7 AUSTRALIAN UNIVERSITIES

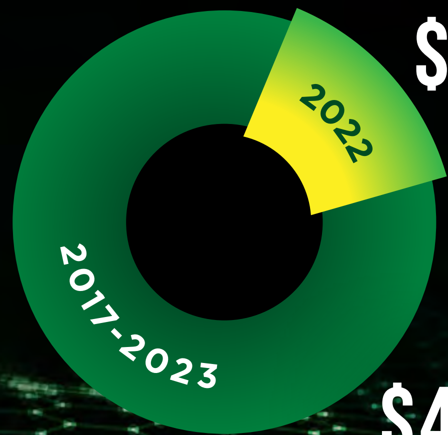
18
INTERNATIONAL PARTNER ORGANISATIONS

41
EARLY CAREER RESEARCHERS

FLEET LAUNCHED

12 June 2018

RESEARCH FUNDING



$6.1M
in 2022

$42.8M
in 2017-2023

Vision

FLEET has had a vibrant and productive year in 2022.

Disruptions to research due to the pandemic subsided in 2022, and international travel slowly returned, enabling increased activities with partners. This allowed FLEET to make maximum use of the capacity and network it has built in the last five years to make excellent progress towards its research goals (see highlights in Director's message p10).

BUILDING FLEET'S LEGACY

As a mature Centre, FLEET has turned its focus from capacity- and network-building to ensuring a lasting legacy beyond the life of the Centre. This process began in 2021 after FLEET's mid-term review, and has blossomed in 2022.

The most visible legacy initiative is the FLEET Translation Program (FTP), inaugurated in 2022. FTP has worked actively to identify FLEET members interested in translating their research, and projects that are promising for translation. The results have been extraordinary: six projects are already funded and another 18 or more prospective projects are in the pipeline. The huge number of translation-ready projects arising from FLEET research, and the eagerness of FLEET researchers to pursue translation of their research, is a pleasant surprise, and we now have the new challenge of finding investors and partners to help fund these promising projects (see more on p26).

Another significant legacy of FLEET will be the increase in participation of women in STEM research, and the increased level of best practice in ensuring equity. FLEET pioneered a Centre-wide search strategy, the Women in FLEET Fellowships, open to women across all areas of FLEET research rather than targeting specific areas. This strategy brought in 68 applicants compared with only 28 female applicants in 15 previous targeted searches combined. In 2022 FLEET broadened this strategy to other groups that are also under-represented in STEM, and appointed four Diversity in FLEET Fellows representing women, LGBTIQA+ and disadvantaged backgrounds.

Through this and other initiatives, FLEET achieved a strong upward trajectory in the proportion of women in the Centre from 2017 to 2020. However, the proportion stalled at around 25% from 2020 to 2022, short of our KPI target of 30%. It is clear that the pandemic significantly hampered FLEET's ability to ensure diversity in hiring, due to a combination of hiring freezes, inability of people to relocate, and the necessity of extending contracts or making direct appointments to support current FLEET staff. FLEET is now working to quantify the reasons for this and to understand how unforeseen shocks can fall inequitably on under-represented groups and set back diversity initiatives, and how we can make equity more 'robust' against such shocks.

FLEET's legacy includes shaping public policy in science and technology in order to pass on the lessons learned by the Centre and to build the environment in which future research centres can thrive and contribute maximally to Australia's wellbeing. In 2022 FLEET gave input to the National Quantum Strategy and the list of Critical Technologies in the National Interest, and FLEET will continue to play a leadership role in shaping Australia's future in quantum materials and electronics technologies research.

QUANTIFYING FLEET'S LEGACY

Going forward FLEET will be working to quantify its legacy. This includes tracking the outcomes of FLEET's training on the careers of our trainees, the uptake and translation of FLEET research, and the effect of FLEET's outreach programs on attitudes towards STEM subjects and public awareness of energy in computation.

We welcome input from all our current and former members and stakeholders, and we would be delighted to hear how FLEET has made a difference to you.

ACHIEVEMENTS

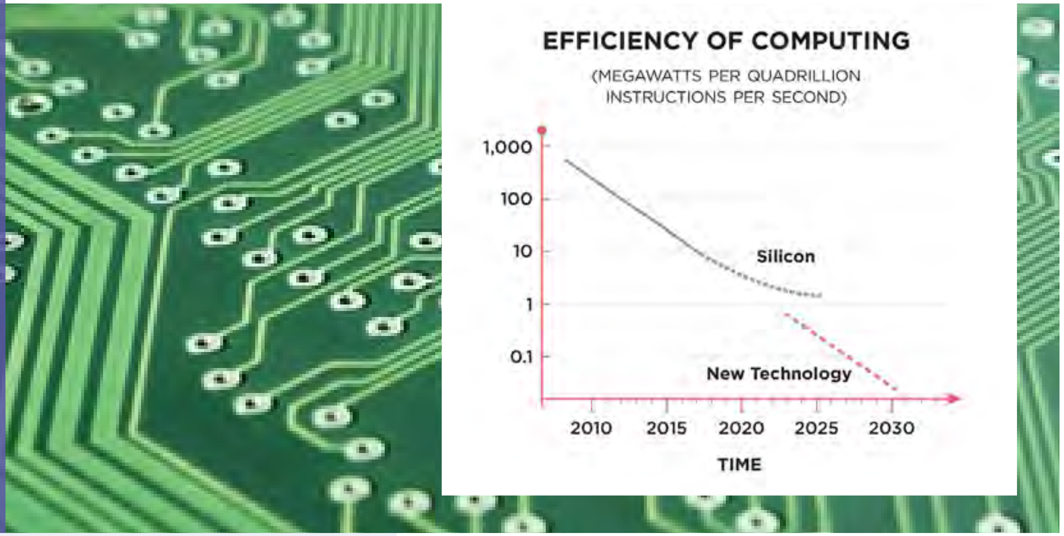
FLEET researchers published 121 peer-reviewed articles in 2022, exceeding our KPI by 20%. More importantly FLEET has maintained its extraordinary trend of publishing high-quality, impactful work; over half (55%) of FLEET's papers in 2022 were in high-impact outlets (impact factor greater than 7).

Communication of FLEET's research to the public continues to excel. We have increased our KPI for media mentions of FLEET research twice, from 40 per year to the high current level of 300 (nearly one per day), which we very nearly accomplished in 2022 with 288 total media mentions. Much of this has been driven by our young researchers, who we have encouraged and trained to write their own press releases, ensuring they can continue to publicise their own work after FLEET communication support ends.

FLEET trained 47 postdoctoral researchers, 62 PhD students and 2 Master's students in 2022. FLEET provided a wide variety of training opportunities for students and ECRs, such as sponsoring students to attend Science meets Parliament and co-organising the Idea Factory research-translation boot camp. Centre members accrued a total of 1274 training workshop attendances in 2022, and 393 non-Centre members attended FLEET training, representing 255% and 131% of our KPIs respectively.

FLEET engages with primary and secondary students and the public at large to foster interest in STEM subjects, especially among under-represented groups, and to educate the public about the societal challenge of energy use in computation. FLEET involves all members in outreach activities, with the strong expectation that every FLEET member (from students through to the Director) will contribute 20 hours each year to outreach. This both powers the Centre outreach program and provides valuable training to students and ECRs. FLEET's outreach program was significantly impeded by the pandemic but returned to nearly full strength in 2022, with 863 hours of outreach by members (72% of KPI), reaching 2738 primary and secondary students (137% of KPI) and 4306 members of the public (86% of KPI).

FLEET's grand challenge



FLEET's mission is to enable the continuing growth of computing, without that growth being throttled by the availability and costs of energy. We will do this by developing a new transistor that can switch at lower energy.

CHALLENGE: A SUSTAINABLE FUTURE FOR COMPUTING

Computing provides overwhelming benefits to the community and economy. FLEET's mission is to enable a sustainable future for computing, not limited by the availability and cost of energy.

FLEET addresses a grand challenge: reducing the energy used in information and communication technology (ICT), which already accounts for about 8% of global electricity consumption and is doubling every decade.

The current, silicon-based technology (CMOS) is 40 years old and reaching the limits of its efficiency.

Fundamental physics indicates 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 January 2021 SRC Decadal plan for semiconductors identifies ever rising energy demands for computing vs. global energy production as a 'seismic shift' that is creating new risk, predicts 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

2021 Annual Report

2022 Annual Report

7 trans-pacific colloquia, 14 research seminars, 2 research workshops, 2 conferences, 3 industry engagement events, 8 professional & research development events

FLEET Translation Program launched

5 IP & commercialisation focused seminars held

AI Matthew Reeves

AI Stefan Maier

AI Jianbo Tang

AI Pankaj Sharma

AI Baoyue Zhang

CI Priyank Kumar
AI Pankaj Bhalla

FLEET ICPS satellite meeting

FLEET 2022 workshop

2022 Gordon Godfrey conference

FLEET Strategic meeting and ECR workshop

12 Women & Diversity in FLEET applicants interviewed

4 Women and Diversity in FLEET fellows starting

Strategic Plan Review

8 students and ECRs at inSTEM diversity conference

3 Carers grants, 4 Write up scholarships, 3 Women & Diversity in FLEET Honours and PhD scholarships offered

2 members trained in industry engagement with Cruxes Innovation

12 members trained in industry engagement with Cruxes Innovation

2022 highlights

40 applicants for Women and Diversity in FLEET fellowships, 12 short-listed, 4 hired

2 students receiving top-up scholarship from a philanthropist

1 new chief investigator strengthens capabilities in FLEET themes 1AB

11 PhD completions

2 provisional patents filed: Electrolytes and additives for rechargeable zinc batteries; nanodroplet synthesis

25 new research collaborations established

3 FLEET AIs awarded an ARC Laureate, an ARC Future and a University Vice Chancellor Fellowship

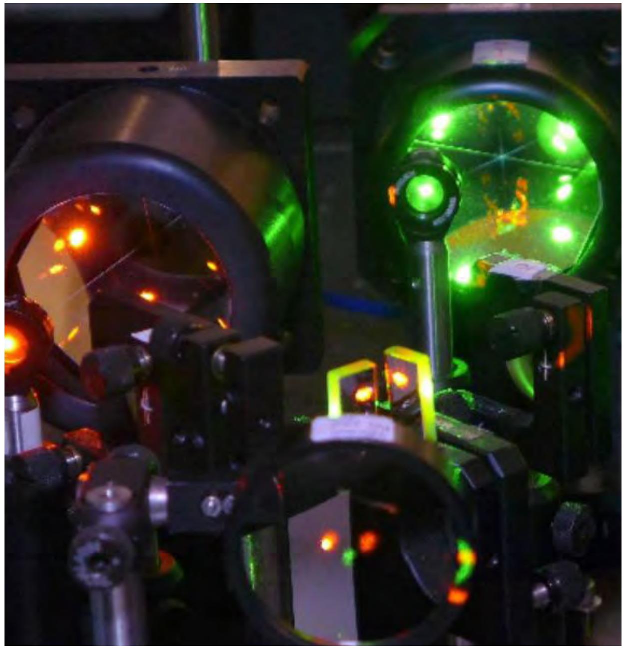
9 FLEET Translation Program applications received, 6 projects funded

FLEET CI led the successful bid for $29M Breakthrough Victoria investment fund

21 engagements with end-users

Message from the Director

2022 marks the fifth full year of FLEET operations. At this stage in the Centre's life, FLEET is focused on demonstrating key research milestones with the highest impact, pathways to translate the most promising research results, and understanding and quantifying the impact that FLEET has made – not only in research, but in training, outreach and diversity. These activities will ensure that FLEET leaves a meaningful and lasting legacy.



NEW STRATEGIC ACTIVITIES

Two major new strategic initiatives announced in 2021 have taken shape in 2022.

FLEET has devoted half a million dollars to the FLEET Translation Program to identify projects ready for translation and enable HDR students, postdocs and investigators to take the next step. FLEET has engaged Michael Harvey to manage the program, directed by Chief Investigator Matt Davis. The program has approved six projects to date and another 18 additional projects have been identified as having prospects for funding. The projects range from prototyping an aqueous zinc battery for low-cost, grid-scale electrical energy storage to developing machine learning software to streamline scanning tunnelling microscopy (see p26).

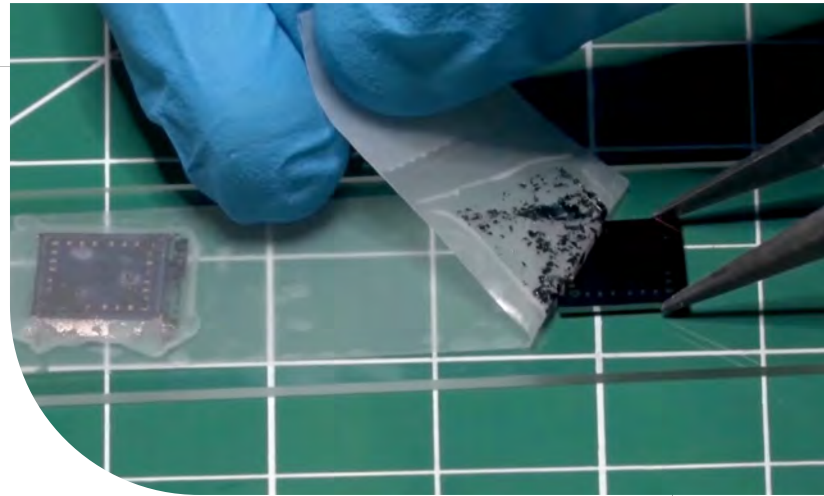
The Centre's Women in FLEET Fellowship program had demonstrated that advertising broadly (across the whole of FLEET) for women candidates could significantly increase the number of qualified applicants, and FLEET briefed the ARC on this successful strategy for increasing diversity in science. In 2022 FLEET expanded this program to other diverse groups under-represented in science, with four new Diversity in FLEET Fellows starting in 2022 with representation from women, LGBTIQA+ and people with disadvantaged backgrounds (see p16).

RESEARCH HIGHLIGHTS

FLEET has made significant progress towards key research milestones. In 2022 FLEET researchers have:

- Shown with detailed modelling that the negative-capacitance, topological, quantum field-effect transistor (NC-TQFET) can operate as a three-terminal device switching at lower voltages, and have refined the NC-TQFET concept, identifying key materials and strategies that will enable operation at significantly lower voltages compared to conventional MOSFET technology
- Identified new prospects for magnetic topological insulators operating at elevated temperatures, and topological structures in ferroelectrics, with potential for ultra-low energy switching at room temperature
- Demonstrated a versatile fabrication scheme for integrating two-dimensional (2D) semiconductors into optical cavities with strong coupling at room temperature, as well as demonstrating lateral trapping of exciton-polaritons at room temperature in 2D semiconductors with a dramatic increase in quantum coherence.

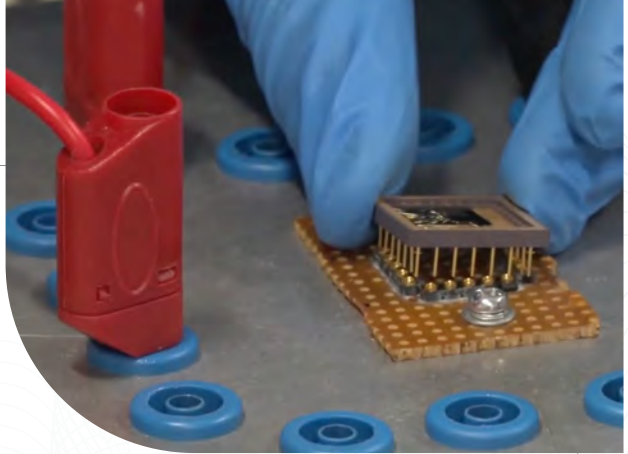
FLEET researchers published 121 peer-reviewed articles in 2022, with 67 (over 55%) in high-impact outlets (impact factor greater than 7). Some of the major research achievements are highlighted.



ENABLING TECHNOLOGY THEME A

Novel quantum materials lie at the heart of FLEET's mission. Introducing magnetism to topological materials has enormous benefits, as magnetic topological states (e.g. the quantum anomalous Hall effect) are truly free of electrical resistance. However, magnetic topological materials operating at elevated temperatures, ideally room temperature, remain a challenge. FLEET has made significant progress against this challenge in 2022. One important strategy for creating magnetic topological structures is to use the proximity of magnetism and topology at an atomically-sharp interface. FLEET researchers demonstrated the quantum anomalous Hall effect in such a structure constructed of a stack of 2D van der Waals materials hetero-structure consisting of an ultra-thin slab of Bi_2Te_3 (a topological insulator) sandwiched between two single layers of $MnBi_2Te_4$ (a magnetic insulator) – see the case study on p58. Ultimately, room-temperature 2D ferromagnetic materials will be needed to create room-temperature topological ferromagnetic structures, and FLEET researchers have made progress in this area by demonstrating that strain can stabilise ferromagnetism above room temperature in the 2D van der Waals material $Cr_2Ge_2Te_6$.

See Technology A p56



ENABLING TECHNOLOGY THEME B

FLEET is working to turn novel quantum materials and effects into useful new devices. In 2022 FLEET researchers demonstrated that the interfacial magnetism in van der Waals materials (in this case the exchange bias between a van der Waals ferromagnet in contact with a van der Waals antiferromagnet) could be controlled electrically using a proton intercalation (see case study on p62). FLEET researchers also demonstrated in 2022 room-temperature negative differential resistance switched by ferroelectricity in a resonant tunneling diode. This demonstration paves the way for novel switches and memory devices based on nanoscale topological defects in ferroelectrics. Ferroelectric control of a 2D semiconductor, which would enable in-memory computation devices, was also demonstrated in 2022.

See Technology B p60

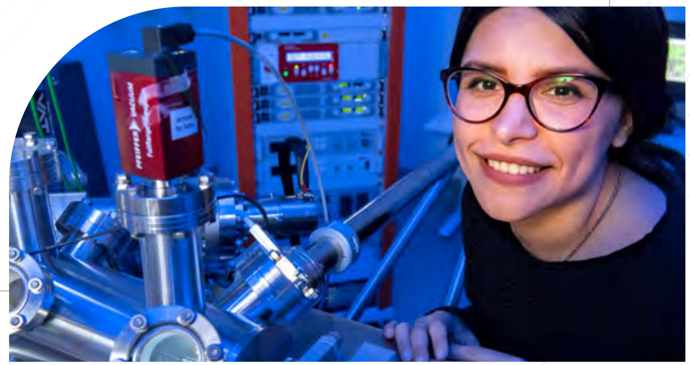
RESEARCH THEME 1

FLEET's Research Theme 1 is creating new transistors in which the topological state of a material is switched on and off. FLEET researchers previously demonstrated that topological switching can be accomplished with an electric field, and the strong spin-orbit coupling in topological materials enabled switching at lower voltages than conventional MOSFETs, a concept called the topological quantum field-effect transistor (TQFET). Further gains in lowering the switching voltage are possible when topological insulators are integrated with ferroelectrics to create a negative-capacitance TQFET.

In 2022 FLEET researchers showed with detailed device modelling that the TQFET using 2D materials called Xenes (analogous to graphene, but with carbon replaced by other elements such as antimony or bismuth) can operate as traditional three-terminal devices with lower switching voltage than conventional MOSFETs. FLEET researchers also uncovered a complex interplay of size confinement and topology in one-dimensional 'ribbons' of Xenes. They found that the topological character of the switching behaviour can be preserved even in narrow ribbons, with the advantage that bandgaps can be increased and the threshold voltage for switching further reduced (see the case study p46). This indicates that TQFETs will show additional benefits when shrunk to the nanoscale.

FLEET researchers are also exploring the potential of 2D materials with the lattice structure known as kagome (after their resemblance to a traditional Japanese basket-weaving technique). Like the graphene or Xene lattice, the kagome lattice hosts Dirac points and potentially can be made topological with strong spin-orbit coupling. However, the kagome lattice has a third band which is nearly dispersionless or 'flat', and can host novel interacting insulating states. In 2022 FLEET researchers constructed and built a designer kagome lattice using a metal–organic framework, and showed that strong interactions drive the emergence of magnetism in this network. Such networks have exciting prospects for electrically-controlled metal–Mott insulator transitions (a MottFET transistor) or electrically-controlled magnetism for spintronics applications.

See Theme 1 on p44



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 inter-particle interactions were not understood when FLEET began.

In 2022 FLEET made major advances in the theoretical understanding and experimental measurements of excitons interacting with each other and with the sea of free fermions in a doped semiconductor (exciton-polarons). The team has produced the quantum virial expansion of exciton-polarons, unifying the trion picture (exciton strongly bound to a single electron) and the Fermi polaron picture (exciton dressed by a sea of fermions). This research is also vital to understanding light-controlled matter and non-equilibrium states in superfluids, and overlaps strongly with FLEET's Theme 3. The team has also experimentally probed the attractive and repulsive interactions of exciton-polarons in the 2D semiconductor WS_2. WS_2 has two distinct Fermi seas living in two separate 'valleys', and the team was able to observe for the first time that exciton-polarons only interact with those coupled to the same Fermi sea. The team was able to apply similar techniques to observe the bi-exciton (strongly-bound pair of excitons) in WS_2.

The FLEET team also continues to press towards demonstrating superfluidity at room temperature in exciton-polaritons in 2D semiconductors. In 2022 the team demonstrated a versatile strategy for fabricating 2D semiconductor devices in optical cavities to achieve strong light–matter coupling at room temperature. The team was also able to demonstrate lateral trapping of exciton-polaritons at room temperature, resulting in extraordinary coherence which may have applications in quantum devices. Room-temperature superfluidity remains tantalisingly close, though not achieved yet!

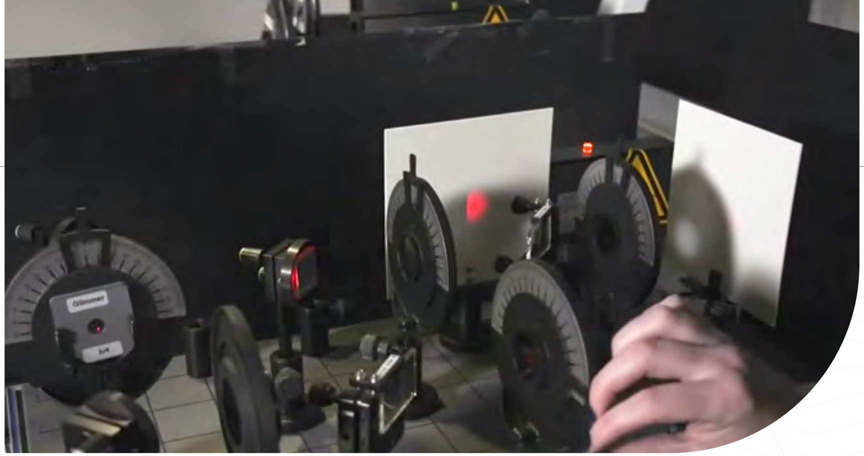
See Theme 2 on p48

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.

FLEET'S CENTRE PRIORITIES IN 2023

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



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 were not understood when FLEET began. In 2022 the FLEET team was able to observe how vortices injected into a superfluid rapidly merge to form stable giant clusters (see the case study p54). The stability of these giant clusters is analogous to the stability of cyclones in the atmosphere, or Jupiter's Great Red Spot.

The FLEET team has demonstrated ultra-fast optical control of graphene's conductivity in 2022, probed at terahertz frequencies in the time domain, and is now poised to demonstrate control of the topological state of 2D materials such as graphene and 2D semiconductors.

See Theme 3 on p52

FLEET'S LEGACY WILL BE MEASURED BY:

- Increased understanding of quantum materials and electronic devices, and new concepts for low-energy electronics at the frontier of science
- The next generation of science leaders, trained in the electronics of tomorrow
- A capacity for quantum materials and electronic devices research in Australia
- Strong links to international excellence, and ongoing partnerships between industry, academia and government, ensuring translation of FLEET science to industry
- Increased diversity in STEM and models for more inclusive research collaboration
- Recognition of the grand challenge of sustainable computing by government and society.

FLEET is also ensuring longevity of other ARC Centres' proven science-outreach outputs: See the case study about the National Science Quiz, ensuring outreach legacy, on p72.

FLEET pathway to impact

2017-2022

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 conducts research into 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

COMMONWEALTH FUNDING
$33.4M

CASH INVESTMENT FROM COLLABORATING ORGANISATIONS
$9.4M

IN-KIND CONTRIBUTION FROM COLLABORATING ORGANISATIONS
$19.6M

EXISTING INFRASTRUCTURES: AUSTRALIAN UNIVERSITIES
7

EXISTING INFRASTRUCTURES: PARTNER ORGANISATIONS
18

INVESTIGATORS
84

ACTIVITIES

POSTDOCTORAL RESEARCHERS BEING TRAINED
52

HIGHER-DEGREE RESEARCH STUDENTS BEING TRAINED
63

WORKSHOPS AND CONFERENCES HOSTED
52

SKILL DEVELOPMENT WORKSHOPS HELD
50

HOME SCIENCE ACTIVITIES DEMONSTRATED
89

OUTPUTS

PUBLICATIONS
502

PATENTS
9

PHD COMPLETIONS
47

POSTDOCTORAL RESEARCHERS TRAINED
64

RESEARCH PRESENTATIONS GIVEN
1211

MEDIA MENTIONS
1773

OUTCOMES

SPIN OFF
LM PLUS TECHNOLOGY - TRANSPARENT CONDUCTIVE OXIDE DEPOSITION

CITATIONS
10,762

FLEET H-INDEX
51

INDUSTRY-FUNDED PROJECTS
2

LINKAGE PROJECTS
3

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

IMPACT

- Capacity for world-leading research in quantum electronic materials and devices
- Australian leadership in beyond-CMOS device research
- Foundational IP for new device concepts and processes
- New technologies using quantum innovations for inclusive, diverse and collaborative STEM culture
- Researchers trained in electronics of tomorrow
- Improved public awareness of areas of FLEET science
- Increased student literacy in STEM.

FLEET pathway to impact
FLEET.org.au/impact

Equity AT FLEET

- Key data
- Equity & diversity at FLEET
- Supporting equity & diversity

Taking concrete steps to improve diversity in science

Equity & diversity key data

>31 CULTURAL BACKGROUNDS

3 WOMEN IN FLEET AND DIVERSITY IN FLEET SCHOLARSHIPS OFFERED

2 FLEET WRITE-UP SCHOLARSHIPS OFFERED

14% — 3 — CHIEF INVESTIGATORS TOTAL 21

12% — 3 — PARTNER INVESTIGATORS TOTAL 25

34% — 13 — SCIENTIFIC ASSOCIATE INVESTIGATORS TOTAL 38

25% — 13 — RESEARCH FELLOWS TOTAL 52

21% — 16 — STUDENTS AND RESEARCH ASSOCIATES TOTAL 77

29% — 6 — ADVISORS AND LIAISONS TOTAL 21

70% — 7 — CENTRE BUSINESS TEAM TOTAL 10

25% % WOMEN IN FLEET (OUT OF 244 CENTRE MEMBERS)

21% % WOMEN RESEARCH STUDENTS AND ASSOCIATES

27% % WOMEN EARLY CAREER RESEARCHERS

* Note data unavailable: indigenous members, people with disability

Number of women also include "non-binary" members

Equity & diversity at FLEET

FLEET's steps to improve women's representation in physics, within the Centre and more widely, have also expanded to encompass wider definitions of diversity.

FLEET continued its commitment to equity and diversity within STEM by funding the first new research fellow positions as part of the Women and Diversity in FLEET Fellowship initiative.

Four new Women and Diversity Fellowships were awarded in 2022; see the case study on p20.

The positions were advertised broadly, with candidates invited to nominate their preference for 'best fit' across all seven FLEET nodes and 21 chief investigators. This method of recruitment helped to identify the best candidates across the full range of Centre research and provided opportunities to explore cross-node projects.

HIGHLIGHTS IN 2022

- Appointing the first Diversity in FLEET Fellows (see case study p20)
- Collaborating to deliver the first inSTEM diversity conference (see case study p70)
- Funding three Women in FLEET Honours and PhD scholarships
- Supporting one PhD student impacted by COVID via the FLEET write-up scholarship
- Extending FLEET carers' awards to three members to assist with family commitments so that conference attendance was possible
- Surveying members' experiences and priorities via the fourth FLEET equity and diversity survey.

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 or 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.

In 2022, FLEET joined with other ARC Centres of Excellence to organise the inaugural inSTEM diversity conference at the University of Queensland. The two-day event was developed for students and ECRs from under-represented or marginalised groups, or their allies. See case study p70.

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

- Aboriginal and Torres Strait Islander cultural learning
- Appropriate workplace behaviour
- Disability awareness
- Fair and effective interviewing for diversity and inclusion
- Modern slavery
- Queer 101.

Individual highlights for diverse populations in FLEET in 2022 include:

- Four Women and Diversity in FLEET fellows to join FLEET
- One scholarship awarded to a FLEET member from the Women in Leadership Development (WILD for STEM) initiative to train with Australian Institute of Company Directors.

WOMEN IN FLEET AND DIVERSITY IN FLEET

Diversity in FLEET Fellowships are open to individuals from any group that is under-represented in Australian STEM, or who have experienced uncommon hardship. Examples include, but are not limited to applicants who:

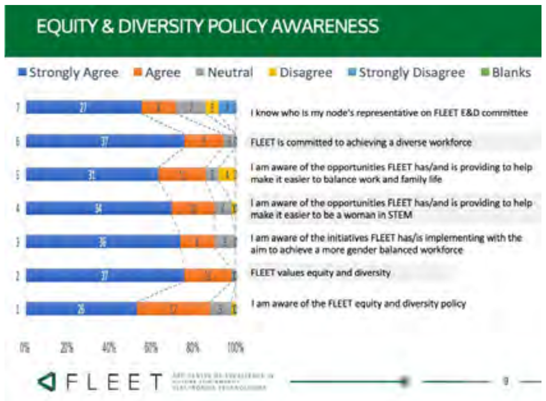
- Identify as Aboriginal and/or Torres Strait Islander
- Have a disability or who cares for a person with a disability
- Identify as LGBTIQA+
- Are from a regional or remote area
- Are from a disadvantaged or low socio-economic background
- Are from a refugee background
- Have experienced uncommon hardship, which could include, but is not limited to, experiences of domestic violence or debilitating health issues.

EQUITY AND DIVERSITY SURVEY

The equity and diversity survey helps FLEET understand the quality and impact of initiatives that have been implemented. In 2022, the survey was distributed for the fourth time; the previous survey was conducted in 2020 when COVID was still having a major impact on our work environment.

The survey received a 32% response rate, exceeding the KPI benchmark of 30%. Of the responses:

- 90% of members reported a high level of satisfaction with FLEET workplace culture
- Almost 90% were aware of the FLEET equity and diversity policy, up from 83% in 2020
- 98% were aware of the initiatives FLEET has implemented to achieve a more gender-balanced workplace, up from 93% in 2020
- Post pandemic, 94% reported having more flexibility of work hours and a feeling that the outcome of their work is more valued than physical attendance, a significant increase from 82% in 2020



- Awareness of recruitment processes to encourage applications from minority and under-represented groups remained static at 75%
- Ready access to necessary facilities (mother's room, prayer room etc.) was 59%; down from 67% in 2020.

Members' suggestions to help increase Centre diversity and inclusiveness included:

- Training to better understand unconscious bias and gender equity
- Providing guidance on how best to work alongside people from other cultures and languages
- Removing names, age and gender from job applications
- Equipping mid-career members with leadership skills.

This valuable feedback will assist FLEET's Equity and Diversity Committee to plan future initiatives as well as understand the legacy of FLEET within this important space.

FLEET will:

- Help increase diversity and inclusion in STEM in Australia
- Provide models for more-inclusive research collaboration.

New Diversity in FLEET and Women in FLEET Fellows

Wider search for FLEET Research Fellows improves Centre diversity

In 2022 FLEET welcomed four new Women/ Diversity in FLEET Fellows, working in disparate roles across the Centre and all contributing to the improved diversity that makes the Centre greater than the sum of its parts.

FLEET's four new Women/Diversity in FLEET Fellows in 2022 are:

- Dr Emma Laird (UQ)
- Dr Yonatan Ashlea Alava (UNSW)
- Dr Mengting Zhao (Monash)
- Dr Grace Causer (Monash).

FLEET's Fellowship will help me overcome the varied setbacks I faced whilst pursuing a career in physics and will allow me to establish myself as an independent researcher within an organisation that highly values the contribution of women physicists.

DR EMMA LAIRD (UQ)

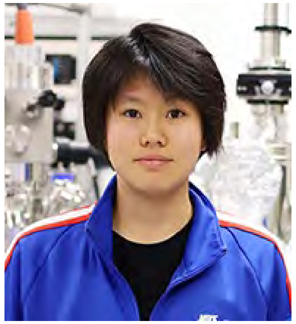
FLEET Research Fellow

The four new fellows were the successful candidates among 35 applicants for Women in FLEET or Diversity in FLEET fellowships.

To maximise the effectiveness of the FLEET research team, and to improve diversity in Australian science, FLEET added new Diversity Fellowships to complement the Centre's Women in FLEET Fellowships. This opens up Centre fellowships to a wider range of applicants from under-represented groups in Australian STEM.

Both categories of fellowship allow for improved flexibility in the location and type of position on offer.

Dr Yonatan Ashlea Alava (UNSW)



Dr Mengting Zhao (Monash)

Scientific recruiting typically advertises highly-focused research roles with specific expertise criteria.

Instead, Women in FLEET and Diversity Fellowships allow for applications from talented individuals whose research interests align with any research area within FLEET, letting applicants nominate investigators they want to work with.

Successful new fellows could have been experimental or theoretical, physicists, chemists or engineers, located at any of seven universities.

I relish the opportunity to work on my leadership and management skills within FLEET while actively seeking out internal and/or external opportunities to continue building my research profile.

DR GRACE CAUSER (MONASH)
FLEET Research Fellow

The flexibility of offering whichever field suits the best applicants available allows the widest choice of applicants, ensuring FLEET has hired the best possible candidates.

The effectiveness of this broader search in allowing FLEET to find excellent researchers who may have been missed in previous, narrowly-targeted searches was confirmed by the remarkable increase in applications for Women in FLEET and Diversity Fellowships.

FLEET has received many more applications for each round of Women in FLEET Fellowships than the combined total from all previous, more-targeted searches.

In the first round alone (2019), FLEET had 68 applicants, whereas 15 previous, more-targeted searches had averaged only two female applicants per search. Another 35 applicants put their names forward for Women in FLEET and Diversity in FLEET Fellowships in 2021–22.

More at FLEET.org.au/diversity2022

Key data +
Research translation +
FLEET Translation Program +

Research translation

FLEET is ensuring sustainable translation of research outcomes

Translation key data

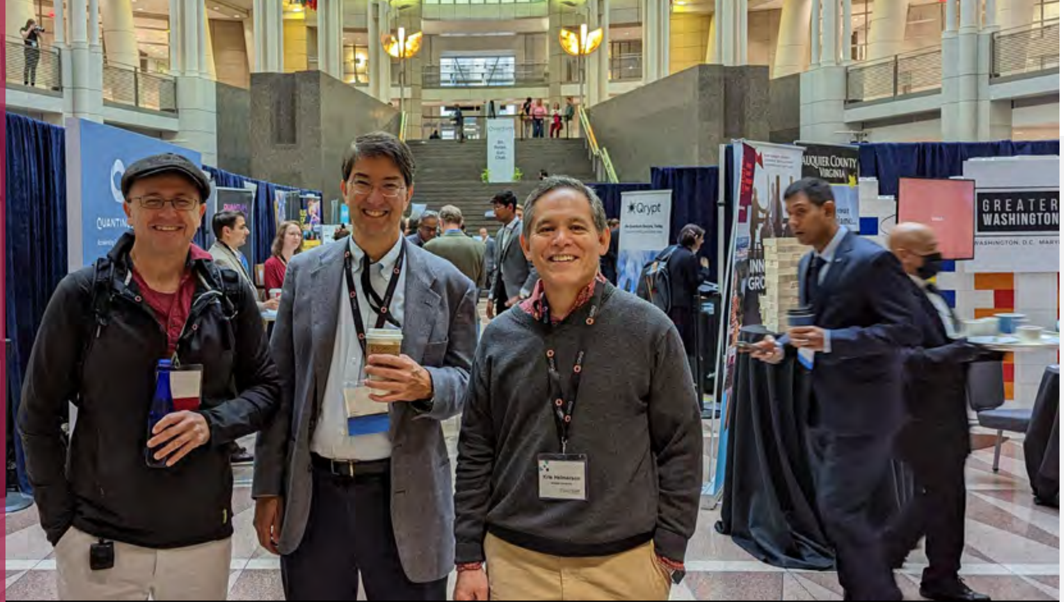
2
PROVISIONAL PATENTS LODGED

7
INDUSTRY BRIEFINGS GIVEN

6
FLEET TRANSLATION PROJECTS FUNDED

$170K
STRATEGIC FUND INVESTED ON TRANSLATION PROJECTS

Research translation



Translating FLEET research to industry innovations with societal impact

FLEET will:

- Translate FLEET science to industry
- Ensure the FLEET research mission continues beyond the current Centre of Excellence's funding cycle (see FLEET.org.au/strategic-plan p21)
- Ensure Australia's next generation of science leaders are prepared for a wide range of future careers, including industry
- Establish strong, lasting links between Australian and international science communities.

With a goal to help transform Australia's electronic technologies and work towards research translation outcomes, FLEET is actively building partnerships and links with research and industry organisations working on novel electronic devices and systems.

ENGAGING WITH INDUSTRY

Progress towards this important goal in 2022 included:

- Initiating the FLEET Translation Program (see p26), with $171,000 funding for six projects approved
- Lodging two provisional patents
- Delivering technical briefings to seven industry organisations
- Increasing engagement with the Australian semiconductor community, and briefing the government on Australian critical technologies
- Training FLEET members on research translation, intellectual property and the commercialisation ecosystem
- Exploring internship opportunities with industry collaborators and partner organisations.

IN 2023 FLEET WILL...

- Run an industry symposium matching the challenges faced by industry representatives to possible FLEET solutions
- Continue the FLEET Translation Program, exploring alternative revenue sources to co-fund FLEET translation projects in the pipeline
- Host the inaugural workshop on Future Electronic Materials Research in Australia (FEMRA)
- Run a training workshop for senior researchers on having an input into government policy.

PATENTS

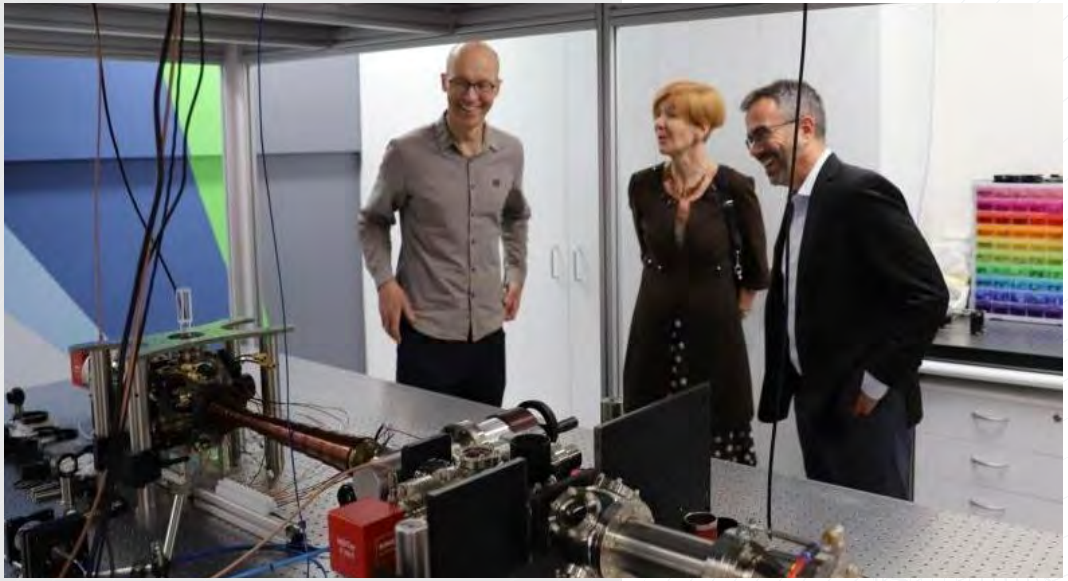
FLEET is committed to boosting the Australian R&D sector and making opportunities to create high-value intellectual property (IP) for transforming electronic technologies by focusing on developing advanced structures that will offer dissipationless electronics.

Two new provisional patents were lodged in 2022:

- Electrolytes and electrolyte additives for aqueous rechargeable zinc batteries
- Improved method of synthesising nanodroplets for catalysts.

FLEET's mission is to enable continuing growth of computing without that growth being throttled by the availability and costs of energy. We aim to do this by developing a new transistor that can switch at lower energy. Along the way, we are creating new IP on material fabrication, processes and theory/modelling methods.

Intellectual property created within FLEET for suites of important quantum materials will serve as the basis for establishing spin-off companies.



An exciting partnership in 2022 links FLEET CI Chris Vale's Swinburne lab with international quantum technologies firm ColdQuanta, announced by the Victorian government.

JUMP-STARTING THE ELECTRONIC MATERIALS COMMUNITY

FLEET's activity and success over five years have galvanised the Australian electronic materials research community.

This opens new windows of opportunities for further scientific advancement of FLEET's discoveries, commercial development of IP created to date, and new research programs stemming from capacity and relationships built up through FLEET's funding period.

In 2023 FLEET will host a future electronic materials research symposium, looking at pathways for Australia's research community to build capacity, networks and funding support addressing 'grand challenges' in electronics materials.

FLEET Translation Program: shepherding scientific discovery towards commercialisation

With a goal to help transform Australia's electronic technologies and work towards research translation outcomes, FLEET is actively building partnerships and links with research and industry organisations working on novel electronic devices and systems.

Program Manager Dr Michael Harvey joined FLEET in 2022 to guide members through the process of identifying promising projects for translation to industry and shepherd them through the process of establishing linkages.

In its first year the program funded six projects.

The program focuses on members, and success is seen in FLEET members trained in translation skills, or getting exposure to the process, as well as translation outcomes delivered.

In addition to meeting members from all seven nodes to identify projects ready for translation, and establishing a rolling call for proposals, Michael also established new training programs in 2022, significantly boosting members' training in translation and commercialisation.

More at FLEET.org.au/translation

I believe that the opportunities provided by the FTP are encouraging our researchers to have a go at projects that they would most likely otherwise not have followed up. Some of them won't come off – but others will – and in the meantime our people gain experience and skills.

PROF MATT DAVIS (UQ)

FLEET Translation Program Director

CASE STUDY

What you see is what you get with pre-characterised TMDs

Novel online WYSIWYG materials platform gets FLEET Translation Program funding

FLEET Translation Program funding approved for a Swinburne/RMIT project led by three PhD candidates will advance a novel online sales platform for prefabricated, high-quality 2D transition metal dichalcogenides (TMDs) and hetero-structures, with a series of optical characterisations, providing customers with confidence that what you see is what you get.

PhD candidates Mitch Conway, Abby Goff, and Jack Muir were awarded $31,000 in funding from the FLEET Translation Program.

Their cross-node collaboration between Swinburne and RMIT aims to create a catalogue of high quality 2D materials, namely transition metal dichalcogenides (TMDs) and their hetero-structures.

"The project will develop prefabricated samples available for purchase on a novel online sales platform which will include a series of optical characterisations, providing confidence that what you see is what you get," explains co-founder Mitch (Swinburne).

The three HDR students believe they have discovered a unique approach in providing pre-characterised samples for researchers so are exploring the feasibility of using their expertise to develop a start-up within the advanced materials manufacturing sector in Australia.

Co-founder Abby (RMIT) says, "The aim of this service is to minimise time needed for in-house synthesis, freeing up researchers time to actually work on the projects that really matter to them".

Exfoliation and characterisation of TMDs is time consuming and requires experience, and TMDs can be difficult to obtain for research groups unequipped for sample synthesis.

"We discovered a FLEET researcher will wait approximately three months to acquire a desired sample, either through collaboration or by making it themselves," says Swinburne student and co-founder Mitch. "We will speed up the process by offering pre-made and -characterised samples with lead times much shorter than what is currently experienced by FLEET academics."

Co-founder Jack (Swinburne) experienced this wait himself when he built a TMD hetero-structure for his research.

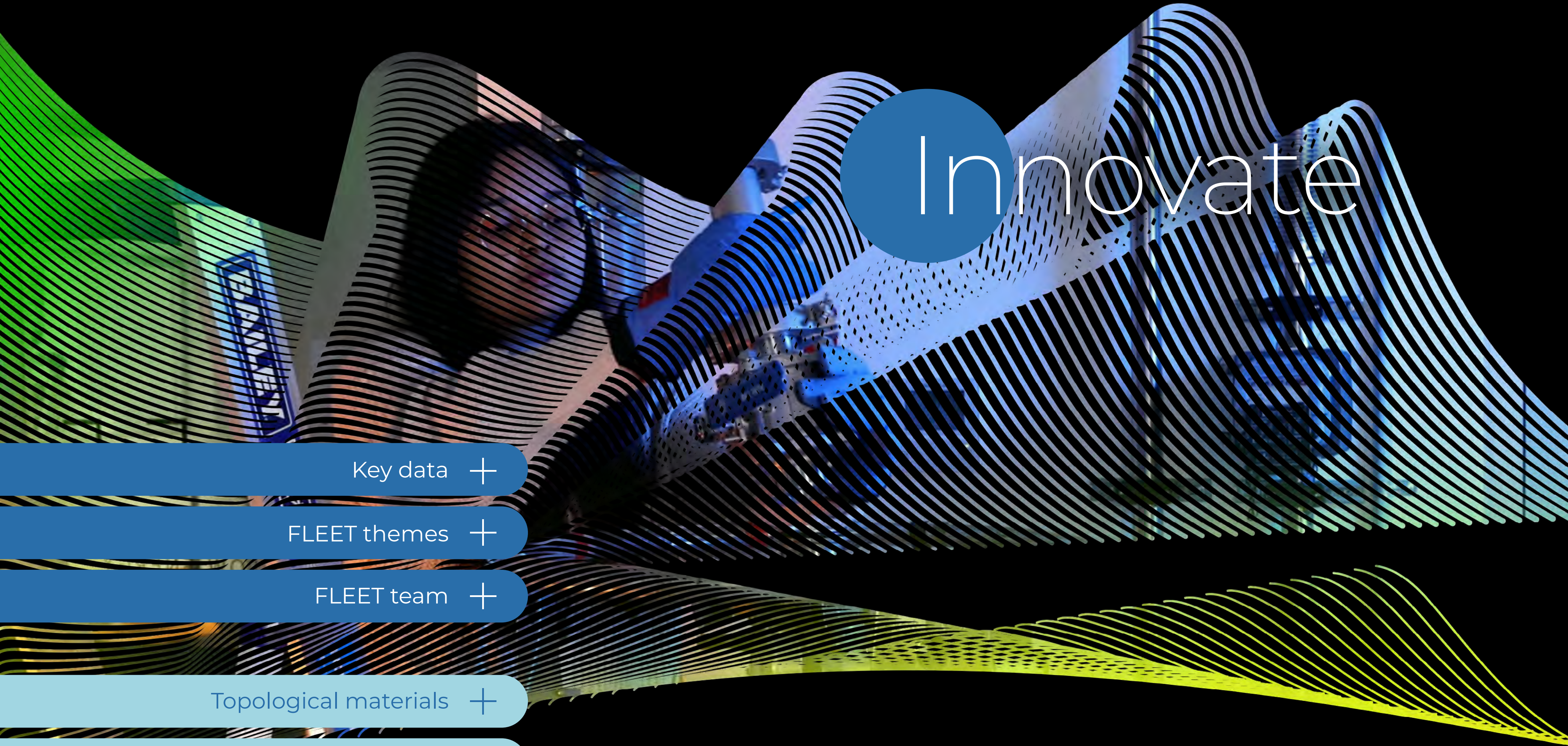
"From start to finish it took months to have it ready for my measurements. Between learning to exfoliate, exfoliating good monolayers, building the device and extensive characterisation, it was a lot of effort and time for something that wasn't guaranteed to work. I'd much rather have spent that time exploring the new and exciting physics of the hetero-structure."

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

The other 2022 funded FTP projects can be viewed on the FLEET website at FLEET.org.au/translation

More at FLEET.org.au/ftp-wysiwyg

Innovate



Key data
FLEET themes
FLEET team
Topological materials
Exciton superfluids
Light-transformed materials
Atomically-thin materials
Nanodevice fabrication

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

FLEET research capabilities and outcomes

$46.7M
VALUE IN RESEARCH GRANTS AWARDED TO FLEET INVESTIGATORS

121
PEER REVIEWED JOURNAL PUBLICATIONS

99
PRESENTATIONS TO EXTERNAL SCIENTIFIC COMMUNITY

49
ARTICLES WITH IMPACT FACTOR > 10

25
INVITED PRESENTATIONS AT INTERNATIONAL MEETINGS

18
ARTICLES WITH IMPACT FACTOR 7-10

CHIEF INVESTIGATORS
21

PARTNER INVESTIGATORS
25

SCIENTIFIC ASSOCIATE INVESTIGATORS
38

FTE RESEARCH FELLOWS
47

HIGHER DEGREE RESEARCH (HDR) STUDENTS
63

FLEET themes

FLEET's approach is multidisciplinary, combining efforts across condensed-matter, cold-atom physics, material 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 p44 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 p48 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 p52 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 p56 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 p60 Technology B

FLEET will:

- Develop and progress new concepts for low-energy electronics
- Increase the global science community's fundamental understanding of quantum materials and electronic devices
- Build Australian research capacity for quantum materials, semiconductors and electronic devices
- Enable discoveries at the scientific frontier.

FLEET TEAM

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, and Fellow of the American Association for the Advancement of Science.

ALEX HAMILTON, UNSW

DEPUTY DIRECTOR & LEADER OF RESEARCH THEME 1 – TOPOLOGICAL DISSIPATIONLESS SYSTEMS

Alex leads Research theme 1 and develops new techniques to fabricate and study both natural and artificially engineered topological materials. An internationally recognised expert on the properties of electrons and holes in semiconductor nanostructures, Alex is 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

CHAIR OF SPECIAL GOVERNANCE COMMITTEE – OUTREACH

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.

KOUROSH KALANTAR-ZADEH, UNSW

Kourosh develops novel 2D semiconducting materials and fabrication techniques for advanced devices, using electron and ion-beam lithography in Research themes 1 and 3 and Enabling technology B.

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

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.

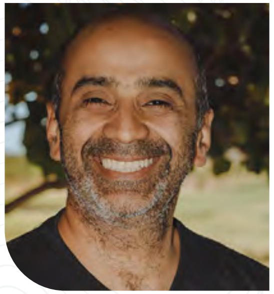
MATTHEW DAVIS, UQ

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

DEPUTY LEADER ENABLING TECHNOLOGIES B

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.

XIAOLIN WANG, UOW

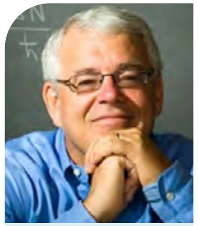
LEADER OF ENABLING TECHNOLOGIES THEME A – ATOMICALLY-THIN MATERIALS

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

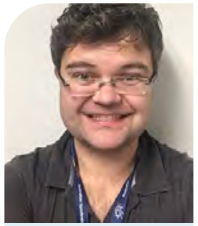
- RESEARCH THEME 1: TOPOLOGICAL MATERIALS
- RESEARCH THEME 2: EXCITON SUPERFLUIDS
- RESEARCH THEME 3: LIGHT-TRANSFORMED MATERIAL
- ENABLING TECHNOLOGY A: ATOMICALLY THIN MATERIALS
- ENABLING TECHNOLOGY B: NANO DEVICE FABRICATION

Partner Investigators



Allan MacDonald
University of Texas

Andrea Perali
University of Camerino



Anton Tadich
Australian Synchrotron

Antonio Castro Neto
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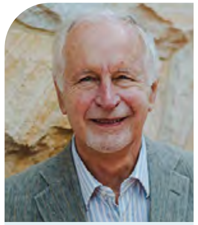
National University of Singapore



David Neilson
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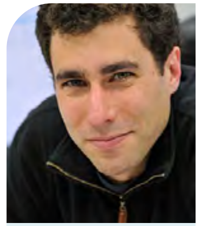
Ferenc Krausz
Max Planck Institute of Quantum Optics



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Grzegorz Sek
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Hai-Qing Lin
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Ian Spielman
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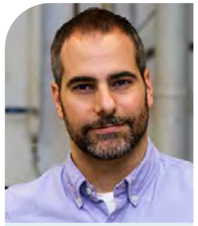

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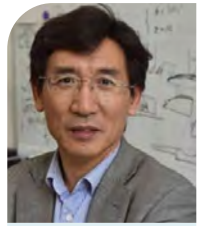

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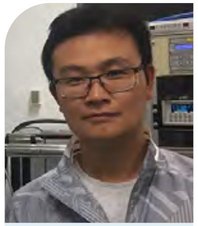
Zhi Li
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Research Fellows


Amelia Dominguez
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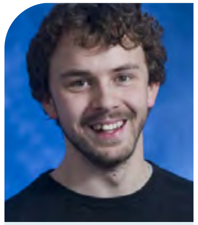
Andrew Groszek
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Angela White
University of Queensland


Anushka Thenuwara
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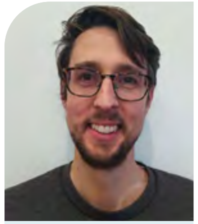
Aydin Keser
University of New South Wales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Daniel Sando
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Eliezer Estrecho
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Emma Laird
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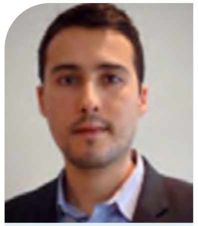
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Frank Yun
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Gary Beane
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Grace Causer
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Guangsai Yang
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Guangyao Li
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Harley Scammell
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Hong Liu
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Ivan Herrera
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Jack Hellerstedt
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Jiong Yang
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Linnan (Leo) Jia
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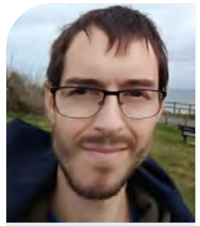
Majid Panahendeh Fard
RMIT University

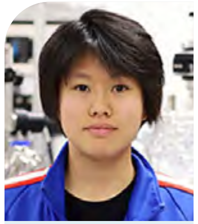

Matthew Edmonds
University of Queensland


Matthew Rendell
University of New South Wales

Research Fellows

Matthias Wurdack

Australian National University

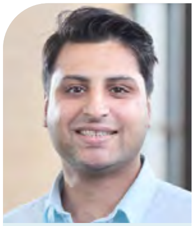


Mengting Zhao

Monash University

Michael Barson

Monash University



Mohammad Ghasemian

University of New South Wales

Mohannad Mayyas

University of New South Wales

Mudassar Nauman

University of New South Wales

Muhammad Nadeem

University of Wollongong

Olivier Bleu

Monash University

Paul Dyke

Swinburne University of Technology

Peggy Qi Zhang

University of New South Wales

Peggy Schoenherr

University of New South Wales

Rhonald Burgos Atencia

University of New South Wales

Sajid Ali

Monash University

Sascha Hoinka

Swinburne University of Technology

Semonti Bhattacharyya

Monash University

Son Ho

RMIT University

Stuart Earl

Swinburne University of Technology

Sultan Albarakati

RMIT University

Tiziana Musso

University of New South Wales

Vivasha Govinden

University of New South Wales

Wafa Afzal

University of Wollongong

Weiyao Zhao

University of Wollongong

Yahua He

University of Wollongong

Yonatan Ashlea Alava

University of New South Wales

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Abhikbrata Sarkar
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Abigail Goff
RMIT University


Abu Parvez
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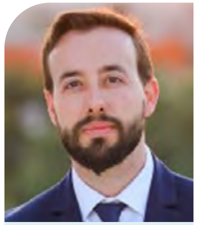
Adam O'Neill
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Benjamin Lowe
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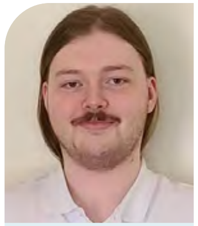
Bernard Field
Monash University


Bianca Fabricante
Australian National University


Caiden Parker
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Enamul Haque
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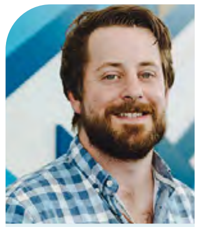
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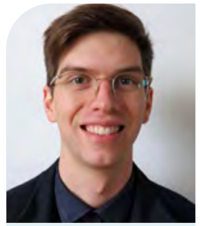
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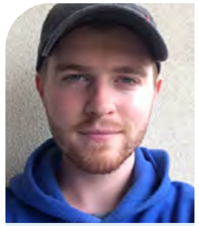
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Ruohan Yu
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Sangeet Kumar
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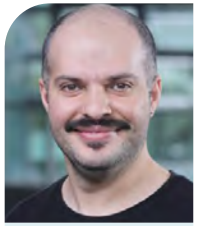
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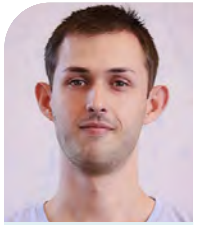
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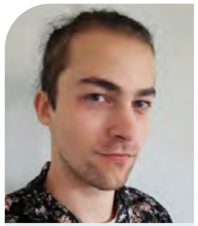
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Haydn Adlong
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University of New South Wales

1

RESEARCH THEME

PROF ALEX HAMILTON

Topological materials

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):
240+ papers
5000+ citations
h-index 36 (Scopus)

FLEET's topological materials research theme seeks 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.

> 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.
>
> **PROF ALEX HAMILTON (UNSW)**
> *Leader, Research theme 1*

FLEET has placed topological insulator electronics devices in the IEEE International Roadmap for Devices and Systems.

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.

FLEET's challenge is 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').

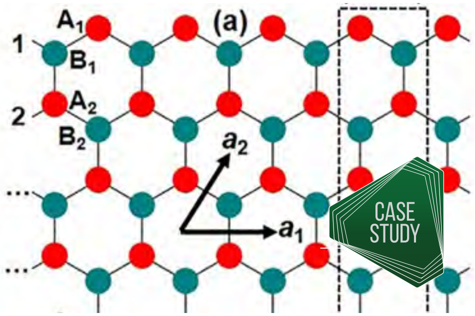
For the new technology to become a viable alternative to traditional transistors, the desired properties must be achievable at room temperature (otherwise, more energy is lost in maintaining ultra-low temperatures than is saved by the low-energy switching).

Approaches used are:

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

A zigzag blueprint for topological electronics

Read our case study



2022 HIGHLIGHTS

- Optimising low-energy topological switching of 2D Xene nanoribbons (see case study p46)
- Forming self-assembled kagome lattices using metal-organic frameworks, with lattice-electron interactions creating novel electronic states towards a low-power 'Mott' transistor
- Theoretically proving topological materials exhibit novel, non-linear electrical and optical properties usable in material characterisation and new device applications
- Achieving novel functionalities and improved properties in piezoelectric materials using carefully controlled crystal growth.

IN 2023 FLEET WILL:

- Build on world-leading techniques FLEET has developed for fabricating nanoscale artificial lattices using both 'bottom-up' self assembly and top-down lithography approaches to study devices with designer quantum properties
- Exploit the flexibility of van-der Waals systems to combine materials with very different electronic and magnetic properties, enhancing the properties of topological insulators towards a functional topological transistor
- Develop theoretical models to quantitatively understand effects of spin-orbit interaction on electronic properties of nanoscale semiconductor devices, and the interplay of magnetism and topology in topological materials.

DEFINITIONS

bandgap The energy gap that defines whether a material is a conductor, insulator or semiconductor; a large bandgap is required for a material to still be topological at room temperature

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

gapless state Zero bandgap, allowing dissipationless electrical conduction

spin-orbit interaction The interaction between electrons' movement and their inherent angular momentum, which drives topological effects

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

QAHE insulator A topological insulator in which conducting edges carry currents in only one direction and are completely without resistance

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

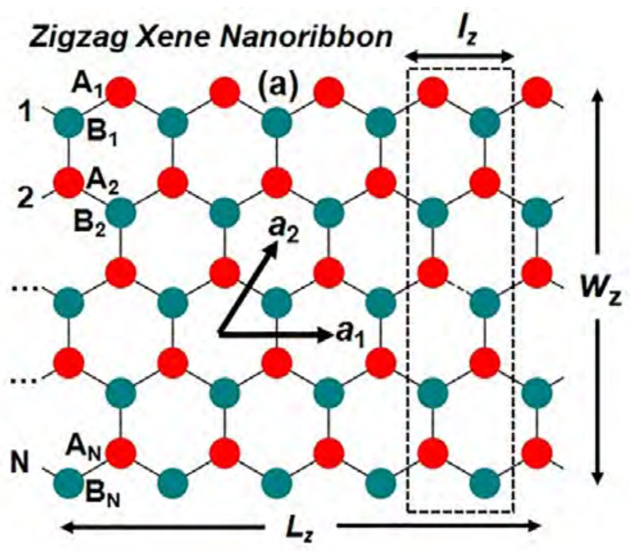
Xene Topological insulators based on group IV and group V materials

More at FLEET.org.au/glossary

CASE STUDY

A zigzag blueprint for topological electronics

Quantum-confined zigzag-Xene nanoribbons could progress ultra-low energy topological computing technologies



A 2022 FLEET collaboration study confirmed the potential of a proposed switching mechanism for a new generation of ultra-low energy topological electronics.

Topological electronics would 'switch' a topological insulator from a non-conducting (conventional electrical insulator) to a conducting (topological insulator) state, whereby electrical current could flow along its edge states without wasted dissipation of energy.

Led by Dr Muhammad Nadeem at the University of Wollongong (UOW), the study also brought in expertise from FLEET Centre collaborators at the University of New South Wales and Monash University.

Two-dimensional (2D) topological insulators are promising materials for topological quantum electronic devices where edge-state transport can be controlled by a gate-induced electric field.

However, a major challenge with such electric-field-induced topological switching has been the requirement for an unrealistically large electric field to close the topological bandgap.

The cross-node and interdisciplinary FLEET research team studied the width-dependence of electronic properties to confirm that a class of material known as zigzag-Xene nanoribbons would fulfil the necessary conditions for operation, namely:

1. Spin-filtered chiral edge states remain gapless and protected against backward scattering
2. The threshold voltage required for switching between gapless and gapped edge states reduces as the width of the material decreases, without any fundamental lower bound
3. Topological switching between edge states can be achieved without the bulk (ie, interior) bandgap closing and reopening.

Graphene was the first confirmed 2D material: a flat sheet of carbon atoms (group IV) arranged in a honeycomb lattice. Now, topological and electronic properties are being investigated for similar honeycomb sheets, collectively called 2D-Xenes, based on group-IV and group-V materials.

As topological insulators these are electrically insulating in their interior but conductive along

their edges, where electrons are transmitted without dissipating any energy (similar to a superconductor).

When a 2D-Xene sheet is cut into a narrow ribbon terminated on 'zigzag' edges, known as zigzag-Xene-nanoribbons, it retains the conducting edge modes characteristic of a topological insulator, which are thought to retain their ability to carry current without dissipation.

It was recently shown that zigzag-Xene nanoribbons had potential to make a topological transistor, which can reduce switching energy by a factor of four. The new FLEET research confirmed the necessary conditions for such devices to function, with respect to edge-state maintenance, low-threshold voltage, and bandgap maintenance during topological switching.

In addition, a topological quantum field effect transistor using zigzag-Xene nanoribbons as a channel material has several advantages in terms of engineering intricacies involved in design and fabrication, avoiding the threshold-voltage isolation challenges of standard MOSFET technologies.

> The Xene nanoribbon can toggle between states (quasi-one-dimensional topological metal with conducting gapless edge states and an ordinary insulator with gapped edge states) with a little tweaking of a voltage knob.
>
> **DR MUHAMMAD NADEEM (UOW)**
> *Lead author, FLEET Research Fellow*

More at FLEET.org.au/zigzag

COLLABORATING FLEET PERSONNEL:

Research Fellow Muhammad Nadeem
UOW

Chief Investigator Alex Hamilton
UNSW

Chief Investigator Dimitrie Culcer
UNSW

Chief Investigator Michael Fuhrer
Monash

Chief Investigator Xiaolin Wang
UOW

This research relates to FLEET milestones M1.2 and M1.7. See page 13 of FLEET's Strategic Plan at FLEET.org.au/strategic-plan

The study was published in *Applied Physics Review* in January 2022.

FLEET is a leading contender in an international race to be the first to achieve superfluid condensate of exciton-polaritons.

PROF ELENA OSTROVSKAYA

Leader, Research theme 2, ANU

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

Research outputs (Elena Ostrovskaya):
160+ papers
5500+ citations
h-index 39 (Scopus)

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.

> Research theme 2 highlights FLEET's collaborative nature, involving cross-disciplinary input between nodes and with several Partner Investigators.
>
> **PROF ELENA OSTROVSKAYA (ANU)**
> *Leader, Research theme 2*

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 are seeking 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 seeks to achieve superfluid flow at room temperature, using atomically-thin semiconductors as the medium for the superfluid.

A drop in the (Fermi) sea

Read our case study

2022 HIGHLIGHTS

- Investigating, experimentally and theoretically, interactions of Fermi polarons in a charge-doped monolayer WS_2 (see case study p50)
- Realising a low-temperature p-type Ohmic contact for electrical transport studies in monolayer WSe_2
- Observing enhancement of coherence and ground state population of room-temperature WS_2 polaritons in an engineered trap
- Developing a scalable method of integrating monolayer WS_2 into polymer-spaced optical microcavities for strong light–matter coupling
- Directly measuring WS_2 biexcitons by multidimensional coherent spectroscopy.

IN 2023 FLEET WILL:

- Continue working towards superfluid condensation of exciton-polaritons in TMD monolayers at room temperature
- Study multi-body complexes and long-lived dark excitons in TMD monolayers, and explore their potential for superfluid condensation
- Continue to investigate the transition to BCS regime in exciton-polariton systems
- Theoretically explore the behaviour of dissipative superfluids in channels.

DEFINITIONS

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

dark excitons Excitons that do not readily recombine to emit light and are therefore long-lived

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

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

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

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

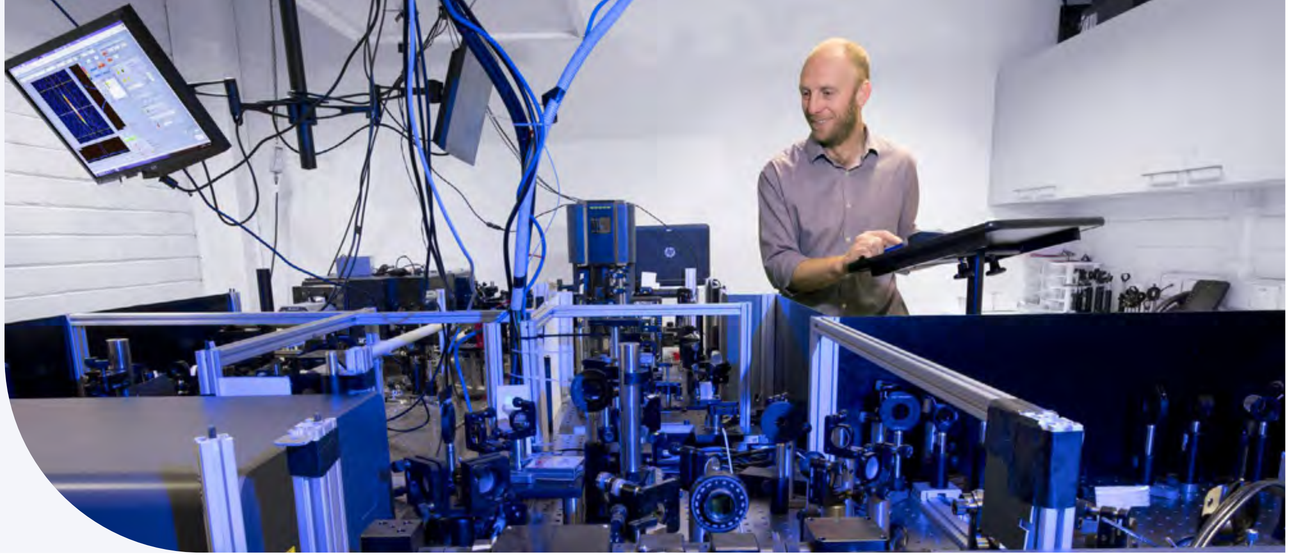
transition metal dichalcogenides (TMDs) Atomically-thin materials with useful physical properties for electronic and opto-electronic devices; used as the optical medium in microcavities

More at FLEET.org.au/glossary

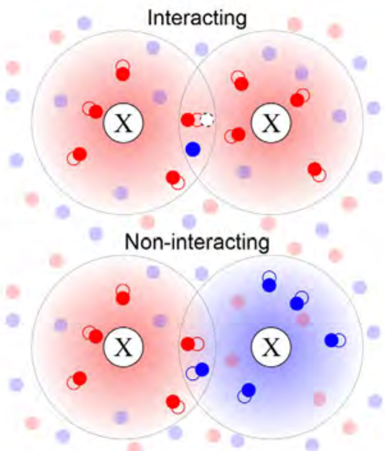
CASE STUDY

A drop in the (Fermi) sea

Understanding Fermi polarons and their interactions



A Swinburne-led FLEET team applying ultra-fast spectroscopy to probe a 2D quantum material, supported by RMIT/Monash theoreticians, identified a novel, cooperatively-bound exciton-exciton-electron state.



Phase-space filling: Two neighbouring excitons (Xs) are 'dressed' by a Fermi sea of ↑ electrons (red circles) displaced from their equilibrium positions (empty circles). Between them, electrons interacting with one exciton are made unavailable to interact with the other exciton.

FLEET research this year provided the world's first measurement of interactions between Fermi polarons in an atomically-thin 2D semiconductor, using ultra-fast spectroscopy capable of probing complex quantum materials.

Centre researchers at Swinburne University found the signatures of interactions between exciton-polarons in experiments on the 2D semiconductor monolayer tungsten disulfide (WS_2).

FLEET collaborators at Monash University and RMIT University developed a theoretical model to explain the experimental signals.

Much of the intriguing physics of 2D semiconducting transition metal dichalcogenides (TMDs), including tungsten disulfide, is described by the creation and interactions of quasi-particles such as excitons (an exciton is an electron bound to a 'hole').

Understanding the interactions of quasi-particle excitations is crucial for efforts to control complex materials (such as high-temperature topological insulators) that could form the basis of future low-energy electronics and quantum information processing.

In a 'doped' semiconductor with many excess electrons, excitons become effective defects in a sea of electrons (known as a Fermi sea), and interactions between excitons and that sea of electrons leads to the formation of new quasi-particles: polarons.

Polaron quasi-particles play an important role in a wide range of systems from cold atomic gases to neutron stars.

Interactions within this Fermi sea were studied using Swinburne's ultra-fast laser spectroscopy facility, which uses multidimensional coherent spectroscopy (MDCS).

Unlike conventional spectroscopic techniques, MDCS can separate interactions from single particle responses to reveal and quantify interactions, revealing an interesting observation: Fermi polarons only interact when they are coupled to the same Fermi sea.

"This was an exciting result; nothing like this had been seen before in these systems, and the physics behind it was new," says lead author FLEET PhD student Jack Muir (Swinburne).

FLEET theoreticians at Monash and RMIT explained the result, demonstrating that repulsive interactions at long range are mediated by a phase-space filling effect, while attractive interactions at short range led to the formation of a cooperatively-bound exciton-exciton-electron state.

Identifying both repulsive and attractive interactions, and the underlying mechanisms, is an important step to fully understanding Fermi polarons and quasi-particle interactions more broadly.

This research relates to FLEET milestones M2.2.2 and 2.2.5. See page 17 of FLEET's Strategic Plan at FLEET.org.au/strategic-plan

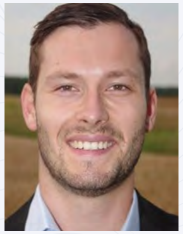
The study was published in *Nature Communications* in October 2022.

With these results we are one step closer to unravelling the rich physics of complex materials and controlling their remarkable macroscopic properties.

JACK MUIR (SWINBURNE)
Lead author, FLEET PhD student

COLLABORATING FLEET PERSONNEL:

PhD student
Jack Muir
Swinburne



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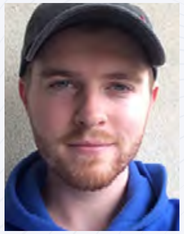

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Swinburne alumnus

Research Fellow
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Chief Investigator
Elena Ostrovskaya
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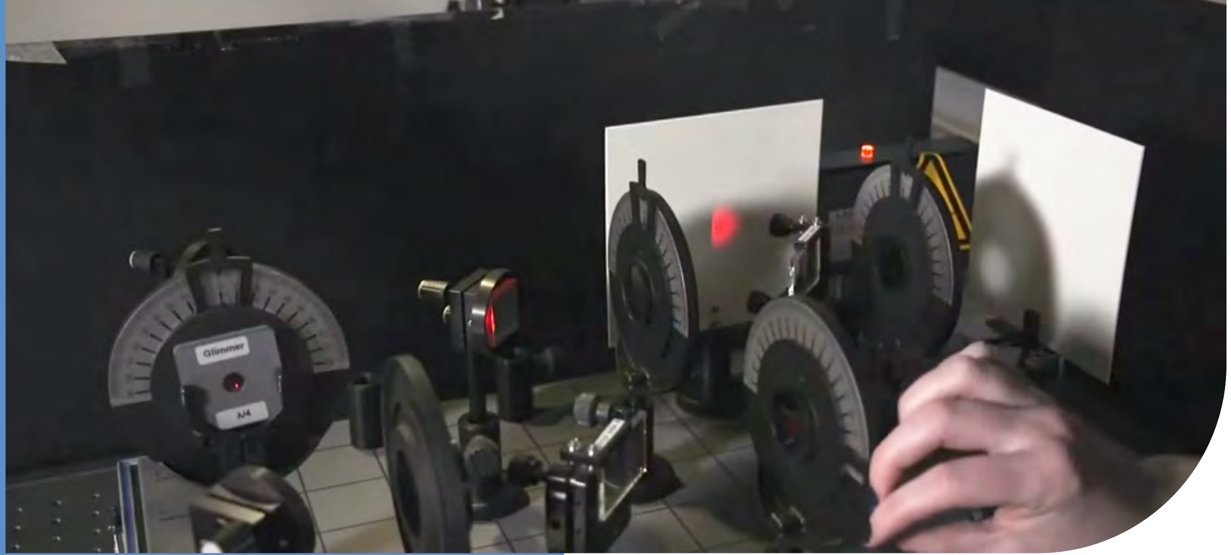
Chief Investigator
Jared Cole
RMIT

Chief Investigator
Jeffrey Davis
Swinburne

Chief Investigator
Meera Parish
Monash

More at FLEET.org.au/FermiSea



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):
115+ papers
5400+ citations
h-index 33 (Scopus)

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

> The ability to use light to modify electron conduction in materials opens up new possibilities in high-speed, low-dissipation electronics.
>
> **PROF KRIS HELMERSON (MONASH)**
> *Leader, Research theme 3*

Light-transformed materials

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) or to shift into a superfluid state (see Research theme 2).

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.

DEFINITIONS

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

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

Floquet control Using periodic, time-dependent fields such as light to modify the band-structure of a material

kicked-rotor system A periodically 'kicked' rotating pendulum (kicked-rotor), which can be realised in the laboratory with atoms periodically kicked by laser pulses

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

spin-orbit interaction The interaction between electrons' movement and their inherent angular momentum, which drives topological effects

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

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

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

More at FLEET.org.au/glossary

Superfluids provide new insight into turbulence

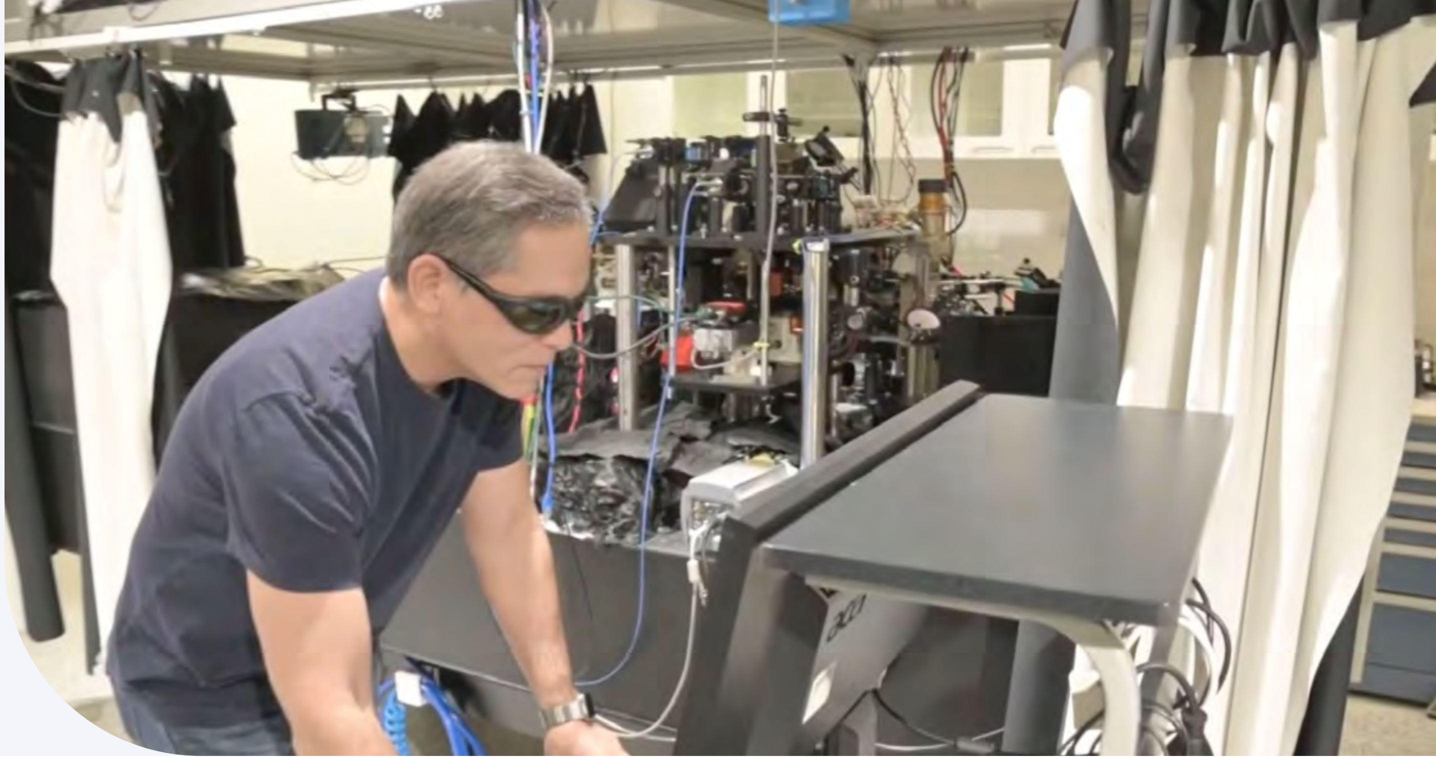
Read our case study

2022 HIGHLIGHTS

- Measuring Higgs mode oscillations in a superfluid gas of fermions (see case study p54)
- Electrostatically controlling broadband terahertz complex conductivity of graphene
- Quantum virial expansion of exciton-polarons
- Experimentally studying polaron–polaron interactions in monolayer WS_2
- Theoretically observing bistability in a driven-dissipative superfluid
- Developing a theory of thermalisation of tunnel-coupled nonequilibrium condensates.

IN 2023 FLEET WILL:

- Demonstrate Floquet control of band structure in graphene
- Continue to develop approaches to identify topological states in Floquet system using terahertz spectroscopy
- Develop quantitative probes for impurities and non-equilibrium dynamics in a 2D Fermi gas
- Investigate quantum kicked-rotor (Floquet) system with spin-orbit coupling
- Demonstrate coherent quantum microscopy probe to image currents in 2D materials
- Further develop theory of driven-dissipative (nonequilibrium) transport of a superfluid.



Superfluids provide new insight into turbulence

University of Queensland researchers from FLEET and a partner Centre of Excellence experimentally validated a decades' old vortex theory, with implications for technological applications of superfluid, such as precision sensing.

Eddies in the quantum state known as a superfluid merge to form large vortices, analogous to how cyclones form in the turbulent atmosphere.

Lead author and theorist FLEET Research Fellow Dr Matt Reeves says the team's results provide experimental validation of the 70-year-old Onsager theory – a model for two-dimensional vortex equilibrium by Nobel Laureate Lars Onsager.

"Large, long-lived vortices like cyclones or Jupiter's Great Red Spot often form out of turbulent fluid flows, such as the atmospheres of planets," says Matt.

Onsager's model explains the existence of these structures, but prior to this 2022 collaborative study with the Australian Research Council Centre of Excellence for Engineered Quantum Systems (EQUS), experiments have tended to conflict with the predictions.

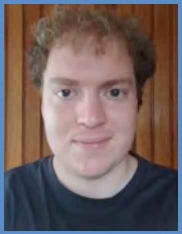
A key complication is that most fluids are viscous, meaning they resist flow. Superfluids, which have no viscosity, are therefore ideal candidates to realise Onsager's model.

Cyclones, such as Jupiter's Great Red Spot, are 'constrained' in the third dimension (up and down), and thus operate as 2D vortices.

The team studied the behaviour of vortices in a Bose-Einstein condensate, a type of superfluid produced by cooling a gas of rubidium atoms to extremely cold temperatures.

COLLABORATING FLEET PERSONNEL:

Masters student Oliver Stockdale
UQ

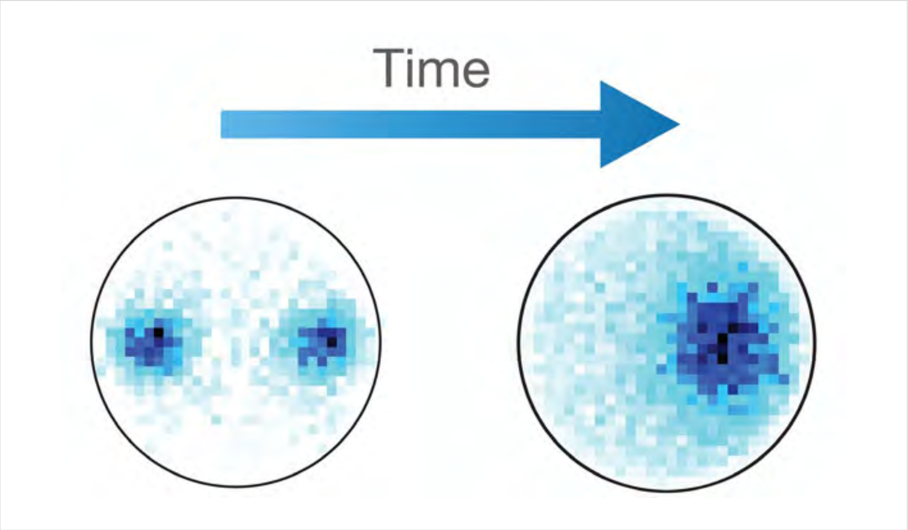


PhD student Timothy Edmonds
UQ

Scientific Associate Investigator Matthew Reeves
UQ

Chief Investigator Matt Davis
UQ

> Our results suggest superfluids can be used to learn new things about turbulence, and will be crucial for the development of precision sensors based on superfluids.
>
> **DR TYLER NEELY (EQUS)**
> *ARC Centre of Excellence for Engineered Quantum Systems*



Vortices in a superfluid merge rapidly into a single cluster.

"We created a thin disc of the superfluid and then used lasers to inject vortices at carefully specified locations," says EQUS researcher Dr Tyler Neely, who led the experiments.

The vortices mixed rapidly, merging into a single large cluster in only a few seconds, much like a large cyclone forming from the turbulent atmosphere.

However, the most exciting thing was the remarkable agreement between theory and experiment – the theory predicted the shape of the final giant vortex structures in the superfluid exceptionally well.

This work answers some of the key outstanding questions from previous work by the team on vortex clusters, which was published in 2019 in Science.

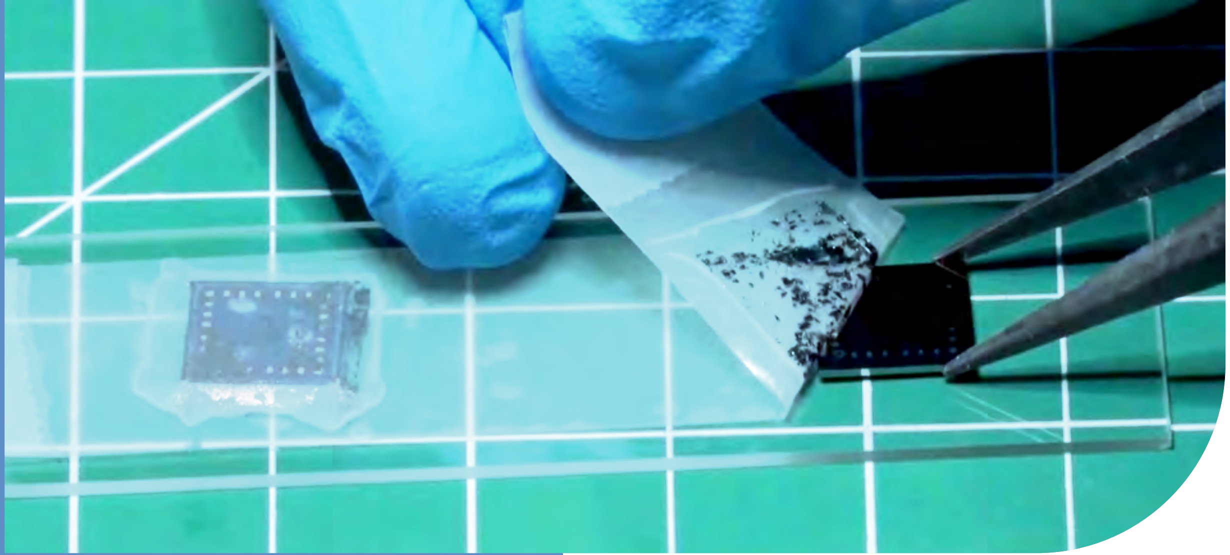
This article first published by ARC Centre of Excellence for Engineered Quantum Systems

This research relates to FLEET milestones M3.1.7. See page 19 of FLEET's Strategic Plan at FLEET.org.au/strategic-plan

The study was published in *Physical Review X* in February 2022.

More at FLEET.org.au/superfluid2022

ENABLING TECHNOLOGY A



Only FLEET can make large-area atomically-thin devices.

PROF XIAOLIN WANG

Atomically-thin materials

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):
290+ papers
17,000+ citations
h-index 65 (Scopus)

> Novel materials are fascinating for both fundamental physics and their great practical applications in electronics.
>
> **PROF XIAOLIN WANG (UOW)**
> *Leader, Enabling technology A*

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 draws 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.

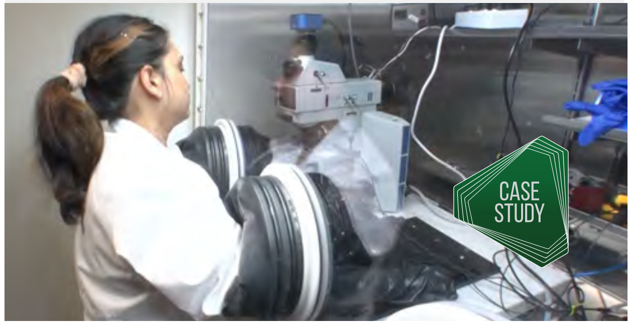
FLEET scientists use other atomically-thin materials in their search for materials possessing the necessary properties for topological and exciton-superfluid states.

2022 HIGHLIGHTS

- Constructing a large-bandgap quantum anomalous Hall insulator heterostructure (see case study p58)
- Observing giant, negative magnetoresistance in titanium-doped 2D ferromagnetic Cr_2Se_3
- Investigating magneto-transport towards tuning Berry phase in magnetic-doped 3D topological insulator BI_2Se_3
- Confirming weak antilocalisation in topological semimetal $Ta_{0.7}Nb_{0.3}Sb_2$ single crystals
- Possible permanent Dirac-to Weyl-semimetal phase transition by ion implantation
- Designing bismuth ferrite multiferroic films with giant piezoelectric properties
- Understanding the role of defects in $LaNiO_3$ rare-earth nickelate films
- Creating topological solitons in bismuth ferrite superlattices
- Developing a new scanning probe technique (tomographic atomic force microscopy) to study topological defects under the surface of a ferroelectric film.

Making a 'sandwich' out of magnets and topological insulators

Read our case study



IN 2023 FLEET WILL:

- Develop resonant tunnelling heterostructures in bismuth ferrite with engineered topological defects
- Develop low-energy switching routes in bismuth ferrite films
- Develop new high-entropy oxide spintronic materials.

DEFINITIONS

bandgap The energy gap that defines whether a material is a conductor, insulator or semiconductor; a large bandgap is required for a material to still be topological at room temperature

ferroelectric materials The electrical equivalent of ferromagnetic materials, with permanent electric polarisation

ferromagnetic materials Materials that can be magnetised

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

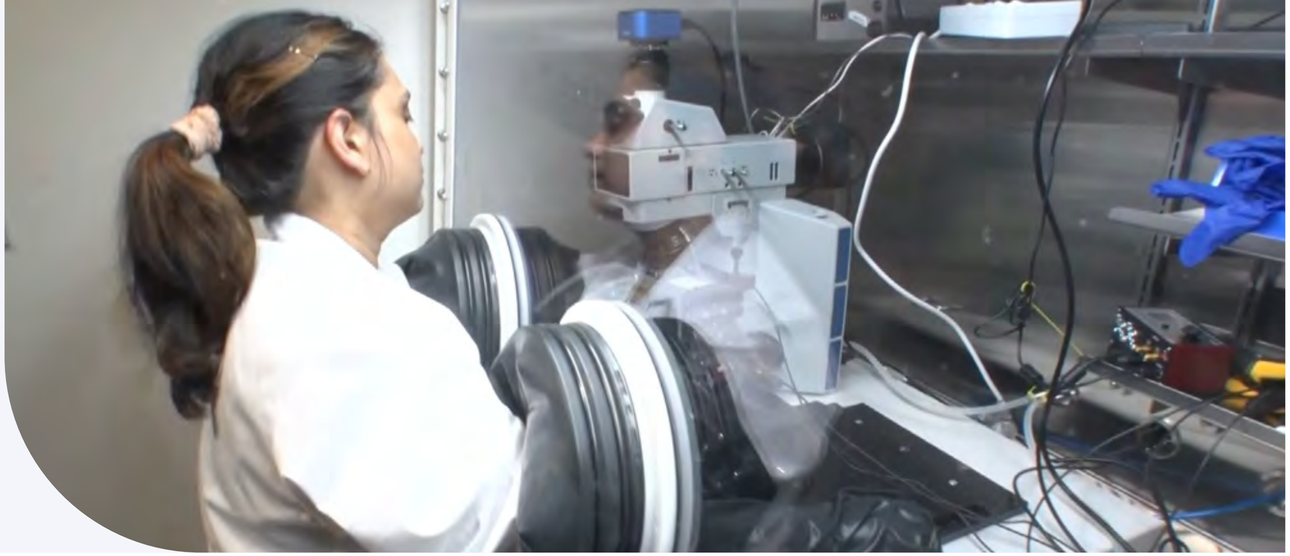
molecular beam epitaxy (MBE) A method used to deposit thin films of single crystals

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

QAH insulator A topological insulator in which conducting edges carry currents in only one direction and are completely without resistance

topological quantum field effect transistor A topological material-based alternative to the silicon-based, CMOS transistors that provide the binary switching and storage of all modern electronics

More at FLEET.org.au/glossary

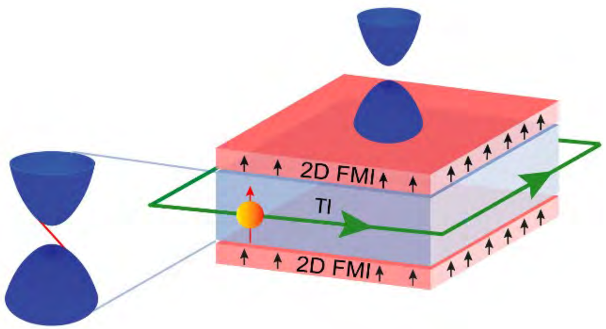


CASE STUDY

Making a 'sandwich' out of magnets and topological insulators

Potential for lossless electronics

A Monash-led FLEET team this year discovered that a structure comprising an ultra-thin topological insulator sandwiched between two 2D ferromagnetic insulators becomes a large-bandgap quantum anomalous Hall insulator.



When two ferromagnets are placed on the top and bottom surfaces of a topological insulator, a gap is opened in the topological surface state, while the edge allows electrons to flow without resistance.

Such a hetero-structure provides an avenue towards viable ultra-low-energy future electronics, or even topological photovoltaics.

In the new hetero-structure, a ferromagnetic material forms the 'bread' of the sandwich, while a topological insulator takes the place of the 'filling'.

The combination of magnetism and band topology gives rise to quantum anomalous Hall (QAH) insulators, as well as exotic quantum phases such as the quantum anomalous Hall effect (QAHE) where current flows without dissipation along quantised edge states.

It is thus a promising pathway towards achieving QAHE at higher temperatures (approaching or exceeding room temperature) for lossless transport applications.

One promising architecture involves a sandwich structure comprising two single layers of $MnBi_2Te_4$ (a 2D ferromagnetic insulator) either side of ultra-thin Bi_2Te_3 (a topological insulator) in the middle. This structure has been predicted to yield a robust QAH insulator phase with a bandgap well above the thermal energy available at room temperature (25 meV).

The new Monash-led study demonstrated the growth of such a hetero-structure via molecular beam epitaxy and probed the structure's electronic structure using angle-resolved photoelectron spectroscopy.

The 2D ferromagnets induce magnetic order (i.e., an exchange interaction with the 2D Dirac electrons) in the ultra-thin topological insulator via magnetic proximity.

This creates a large magnetic bandgap, with the hetero-structure becoming a QAH insulator, such that the material becomes electrically conducting along its one-dimensional edges while remaining electrically insulating in its interior.

The almost-zero resistance along the 1D edges of the QAH insulator are what make it such a promising pathway towards next-generation, low-energy electronics.

Inducing sufficient magnetic order to open a sizeable bandgap is challenging due to the influence of an abrupt interface voltage due to lattice mismatch between the adjacent materials.

"To minimise that undesired interface potential we needed to find a 2D ferromagnet with similar chemical and structural properties to the three-dimensional (3D) topological insulator," says lead author PhD student Qile Li (Monash).

"This way, instead of an abrupt interface potential, there is a magnetic extension of the topological surface state into the magnetic layer. This strong interaction results in a significant exchange splitting in the topological surface state of the thin film and opens a large gap," says Li.

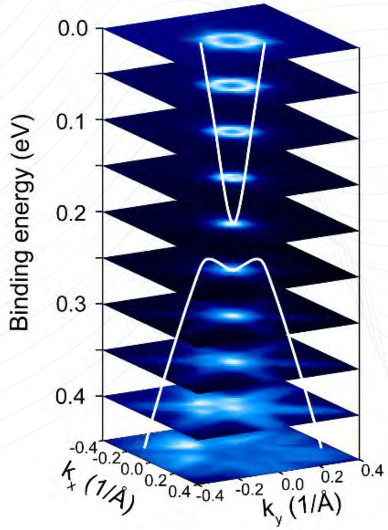
A single-septuple layer of the intrinsic magnetic topological insulator $MnBi_2Te_4$ is particularly promising, as it is a ferromagnetic insulator with a Curie temperature of 20 K.

> These findings provide insights into magnetic proximity effects in topological insulators, which will move lossless transport in topological insulators towards higher temperature.
>
> **A/PROF MARK EDMONDS (MONASH)**
> *Lead author, FLEET Scientific Associate Investigator*

"More importantly, this set-up is structurally very similar to the well-known 3D topological insulator Bi_2Te_3 with a lattice mismatch of only 1%," says A/Prof Mark Edmonds, who is an associate investigator in FLEET.

The research team grew the ferromagnet/topological/ferromagnet hetero-structures and investigated their electronic band structure at the Advanced Light Source, Berkeley, USA.

The magnetic origin of the 75 meV bandgap was confirmed by the observing the gap vanishing above the Curie temperature (where magnetisation ceases), as well excellent agreement with density functional theory calculations.



Angle-resolved photoelectron spectroscopy measurements allow direct measurement of the size of the bandgap opening in the topological surface state, as well as visualisation of the strength of the hexagonal warping.

COLLABORATING FLEET PERSONNEL:

PhD student Qile Li
Monash

Research Fellow Chi Xuan Trang
Monash alumnus

Scientific Associate Investigator David Cortie
UOW

Scientific Associate Investigator Mark Edmonds
Monash

Chief Investigator Nikhil Medhekar
Monash

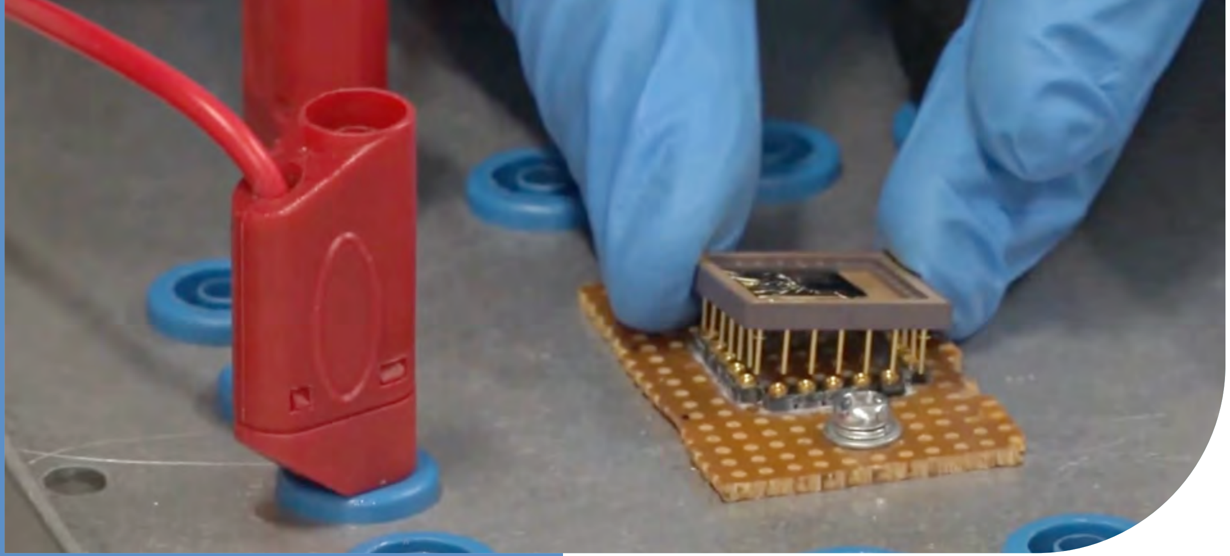
This research relates to FLEET milestone/s M1.3a and M1.7. See page 13 of FLEET's Strategic Plan at FLEET.org.au/strategic-plan

The study was published in *Advanced Materials* in March 2022.

More at FLEET.org.au/sandwich

B

ENABLING TECHNOLOGY



A/PROF LAN WANG

Nanodevice fabrication

Leader, Enabling technology B, RMIT University

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
3500+ citations
h-index 34 (Scopus)

FLEET is a great platform from which to establish collaborations with local and international researchers, allowing us to share ideas and work together.

A/PROF LAN WANG (UOW)
Leader, Enabling technology B

FLEET's research sits at the very boundary of what is possible in condensed-matter physics. Thus, nanoscale fabrication of functioning devices will be 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.

Manipulating interlayer magnetic coupling in vdW hetero-structures

Read our case study

2022 HIGHLIGHTS

- Manipulating interlayer magnetic coupling in van-der Waals hetero-structures (see case study p62)
- Realising room-temperature, electrically-tuned magnetic phase transition in vdW materials
- Achieving resonant tunnelling in ferroelectric heterostructures, including polarisation-mediated negative differential resistance
- Strategy for single-gate operation of a topological quantum field-effect transistor to beat Boltzmann's tyranny
- Showing that proximity coupling to an antiferromagnet can simultaneously beat Boltzmann's tyranny and preserve the dissipationless "ON" state
- Demonstrating Ga_2O_3 glass as a protective layer for graphene which reduces the temperature-dependent resistivity.

IN 2023 FLEET WILL:

- Work towards realising room-temperature magnetic proximity effect in vdW hetero-structures
- Work towards realising room-temperature spin-transport devices and spin-torque devices based on vdW hetero-structures.

DEFINITIONS

ferromagnetic materials Materials that can be magnetised

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

spin-orbit interaction The interaction between electrons' movement and their inherent angular momentum, which drives topological effects

Spintronics Electronics systems using the quantum 'spin' property of electrons (e.g. up or down), in addition to electronic charge (+ or –)

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

topological transistor A topological material-based alternative to the silicon-based CMOS transistors that provide the binary switching and storage of all modern electronics

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

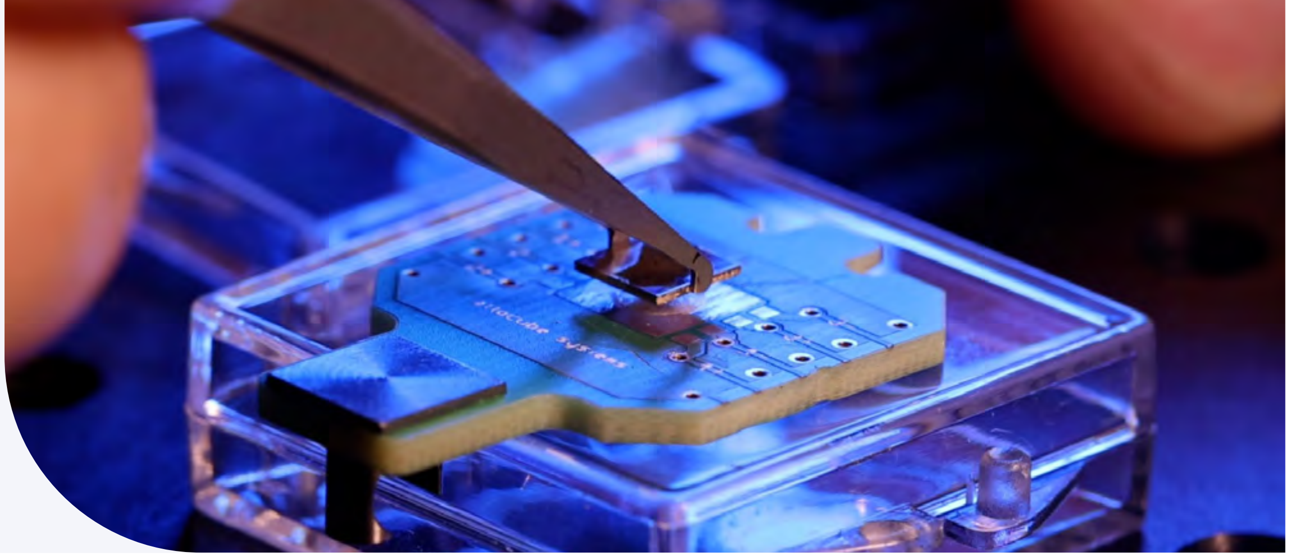
vdW hetero-structure A structure made by stacking layers of different vdW materials

More at FLEET.org.au/glossary

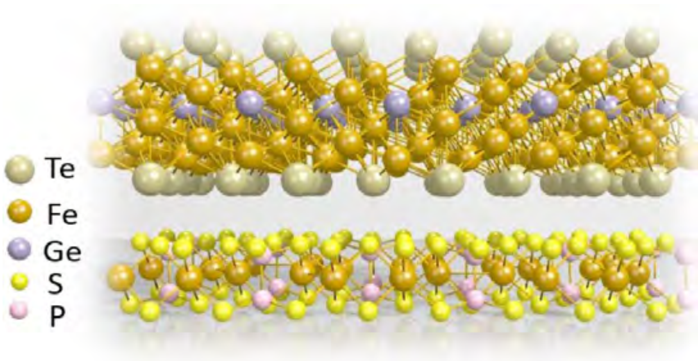
CASE STUDY

Manipulating interlayer magnetic coupling in vdW hetero-structures

Electrical gate control in vdW hetero-structures towards future spintronics



A FLEET RMIT-led international collaboration in 2022 observed, for the first time, electric gate-controlled exchange-bias effect in a van der Waals (vdW) hetero-structure, offering a promising platform for future energy-efficient, beyond-CMOS spintronics.



A heterostructure is constructed with an antiferromagnetic lower layer ($FePS_3$) and a ferromagnetic upper layer (Fe_5GeTe_2).

This new form of gate control would provide scalable, energy-efficient spin-orbit logic, which is very promising for beyond-CMOS devices in future low-energy electronic technologies.

It is the first successful significant manipulation of the exchange-bias effect (which is caused by interlayer magnetic coupling), which has been a significant goal in spintronics.

Electrical gate-manipulated exchange-bias effects in such magnetic hetero-structures enable scalable, energy-efficient spin-orbit logic, with the 'blocking' temperature of the exchange-bias effect effectively tuned via an electric gate.

This would allow the exchange-bias field to be turned 'ON' and 'OFF' in future spintronic transistors.

The FLEET-led collaboration of researchers at RMIT University and South China University of Technology confirmed for the first time the electric control of exchange-bias effect in a vdW hetero-structure comprising antiferromagnetic (AFM) and ferromagnetic (FM) layers.

Such vdW magnetic hetero-structures provide an ideal platform for exploring interfacial magnetic-coupling mechanisms, boosting the development of vdW magnetic and spintronic devices.

FLEET Research Fellow Dr Sultan Albarakati (RMIT)

The exchange-bias effect originates from the AFM–FM interface coupling-induced unidirectional anisotropy.

"We decided it was time to utilise our experience in vdW hetero-structure-based nanodevices and gate control towards control magnetic properties in FM/AFM bilayers," says the study's first author, FLEET Research Fellow Dr Sultan Albarakati (RMIT).

The team was also familiar with proton intercalation, which is an effective tool for modulating materials' charge density.

COLLABORATING FLEET PERSONNEL:

PhD student
Lawrence Farrar
RMIT

PhD student
Meri Algarni
RMIT

Research Fellow
Sultan Albarakati
RMIT

Research Fellow
Cheng Tan
RMIT

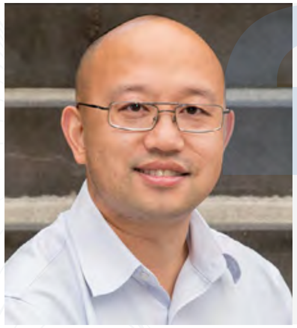
Research Fellow
Guolin Zheng
RMIT
alumnus

Scientific Associate Investigator
Michelle Spencer
RMIT

Partner Investigator
Mingliang Tian
China High Magnetic Field Laboratory

Chief Investigator
Lan Wang
RMIT

Chief Investigator
Xiaolin Wang
UOW



This study is a significant step towards vdW hetero-structure-based magnetic logic for future low-energy electronics.

A/PROF LAN WANG (RMIT)
Corresponding author, FLEET Chief Investigator

The team's expertise with magnetic materials informed materials chosen for the successful structure: a three-layer nanodevice featuring a ferromagnetic layer, antiferromagnetic layer and solid proton conductor.

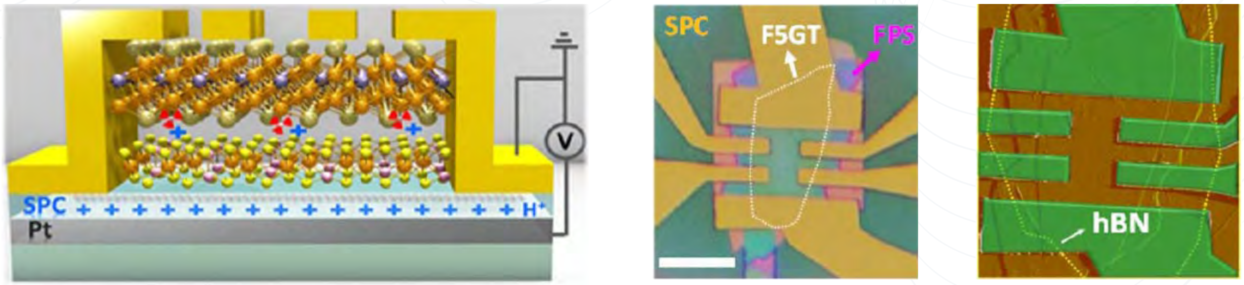
The team then observed the shift of exchange-bias fields under different gate voltages.

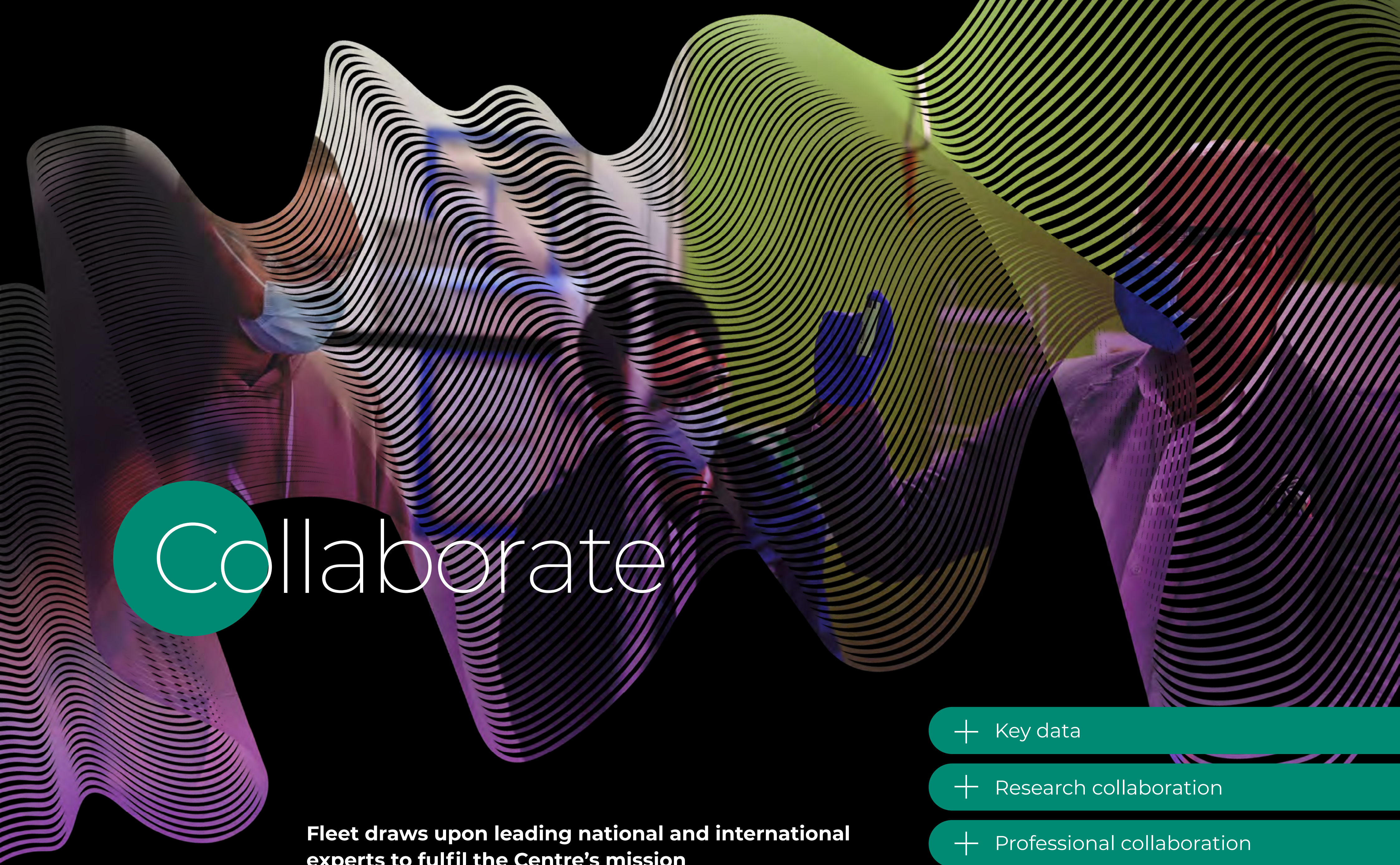
"The blocking temperature of the exchange-bias effect can be effectively tuned via an electric gate. And more interestingly, the EB field can be switched 'ON' and 'OFF' repeatedly under various gate voltages," says co-author Dr Guolin Zheng (RMIT).

This research relates to FLEET milestones M1.14 and M1.15. See page 14 of FLEET's Strategic Plan at FLEET.org.au/strategic-plan

The study was published in *Nano Letters* in August 2022.

More at FLEET.org.au/magcoupling





Collaborate

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

+ Key data

+ Research collaboration

+ Professional collaboration

Collaborate key data

RESEARCH SEMINARS & CONFERENCES ORGANISED
24

25
NEW RESEARCH COLLABORATING ORGANISATIONS ESTABLISHED

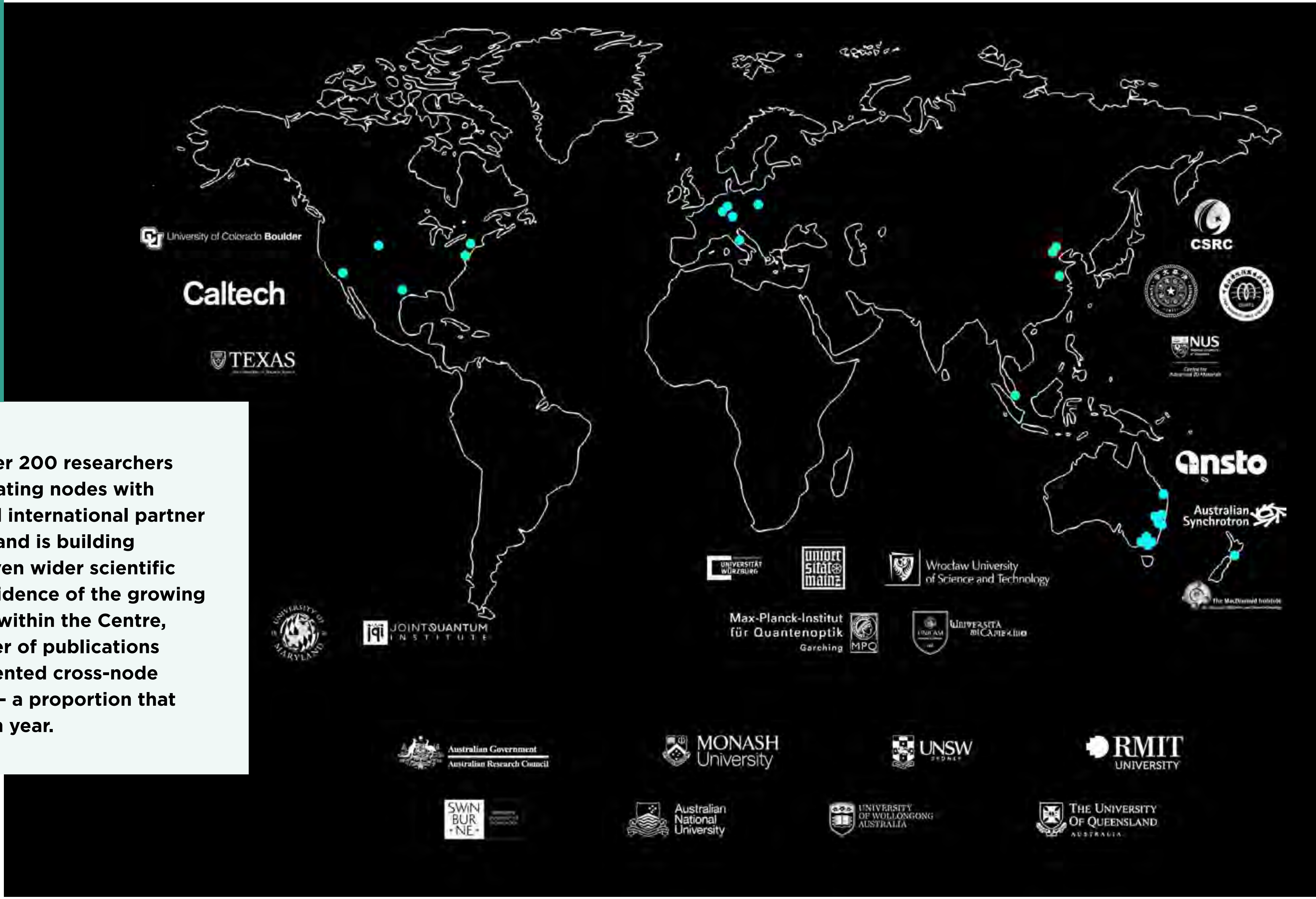
FLEET MEMBERS VISITING PARTNER ORGANISATIONS
15

NEW ORGANISATION LINKS FOR TRAINING & OUTREACH ESTABLISHED
11

21
END-USER RELATIONSHIPS ESTABLISHED

Research collaboration

FLEET links over 200 researchers across participating nodes with 23 national and international partner organisations, and is building links with an even wider scientific network. As evidence of the growing collaborations within the Centre, almost a quarter of publications in 2022 represented cross-node collaborations – a proportion that has grown each year.



FLEET's extensive network of 23 leading national and international research partners is key to fulfilling the Centre's mission.

FLEET is building synergies between Australian research communities. The percentage of cross-node publications has grown each year from 3% in the Centre's first year (2017) to 23% in 2022, reflecting the importance of inter-node research in FLEET.

Publications involving multiple chief investigators, associate investigators, partner investigators and/or nodes make up 69% of all FLEET publications.

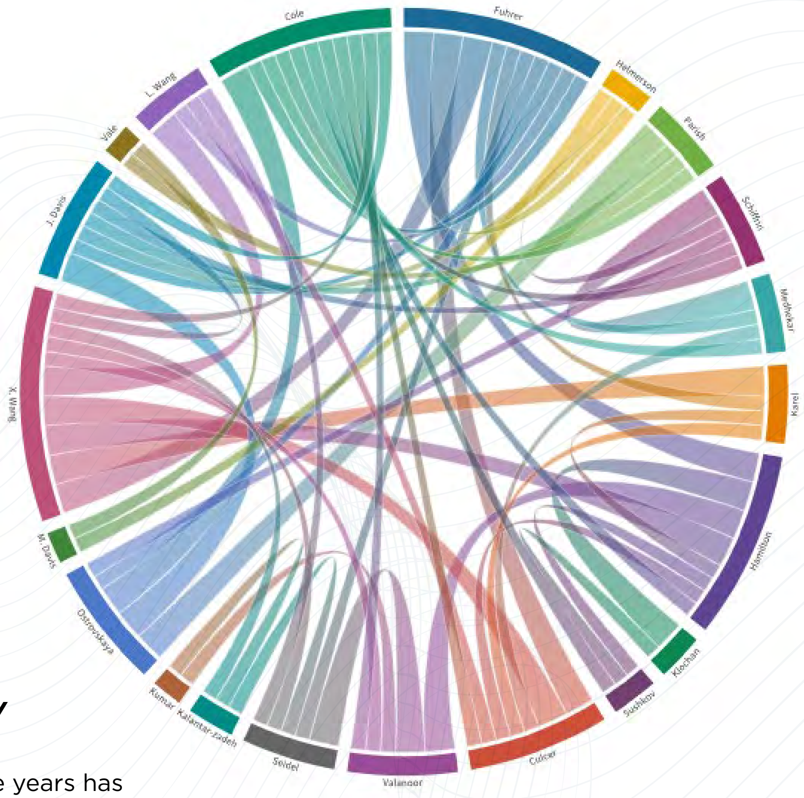
Out of 121 publications:

- 28 papers involved multiple FLEET nodes
- 21 have multiple chief investigators
- 13 were co-published with FLEET partner organisations
- 63 were co-published with scientific associate investigators
- 13 were co-published with other Centres of Excellence
- 84 involved multiple chief, associate or partner investigators and/or nodes.

FLEET will:

- Establish strong, lasting links between Australian and international science communities
- Maximise ongoing benefit to Australia from established FLEET networks and linkages.

Mapping 2022 collaboration between CIs. Connections indicate active research projects



Interactive chart at FLEET.org.au/collaboration

JUMP-STARTING THE AUSTRALIAN ELECTRONIC MATERIALS COMMUNITY

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.

It also represents lasting value to Australia's science efforts.

In June 2022, capitalising on the presence in Australia of many leading semiconductor scientists at the International Conference on the Physics of Semiconductors (ICPS) in Sydney, FLEET hosted a one-day ICPS Satellite Symposium. Around 50 members and guests attended the symposium in which Australian and international experts discussed 2D materials, topological materials and spin phenomena, and exciton and exciton-polariton science.

In March 2023, FLEET will host a Future Electronic Materials Research in Australia workshop, looking at pathways for Australia's research community to build capacity, networks and funding support addressing 'grand challenges' in electronics materials.

HOSTING RESEARCH SEMINARS

FLEET's continuing research seminar series focused in 2022 on presentations from PhD students and ECRs, improving members' public communication skills and exposing their research to a wider audience outside their own research groups.

In 2022, without COVID restrictions, the Centre took advantage of the ability to conduct hybrid workshops (i.e. including both online and in-person audiences) wherever possible.

FLEET ran 14 seminars in 2022: 10 presented by FLEET early-career researchers (ECRs) and four joint seminars introducing Centre members to relevant research from the ARC Centre of Excellence for Transformative Meta-Optical Systems (TMOS), Monash School of Physics and Astronomy, Monash Materials Science and Engineering, and UNSW.

The seminars cumulatively attracted an audience of almost 400 with around 70 participants from outside the Centre.

In addition, FLEET conducted one seminar on research translation and five intellectual property seminars with FLEET Translation Program Manager Michael Harvey, conducted at different FLEET nodes.

US–Australian transpacific condensed-matter talks

FLEET's Trans-Pacific Colloquium series continues to maintain links between physics communities in Australia and North America.

Since its initiation, the series has hosted 28 colloquia with speakers alternating between North American researchers and Australian-based universities. Gender mix has been an ongoing focus, and 50% of the speakers in 2022 were women.

In 2023 the series will expand to include European-based speakers.

The series' organisation committee is led by FLEET Associate Investigators Dr Dmitry Efimkin (Monash) and Prof Susan Coppersmith (UNSW), 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.

Professional collaboration

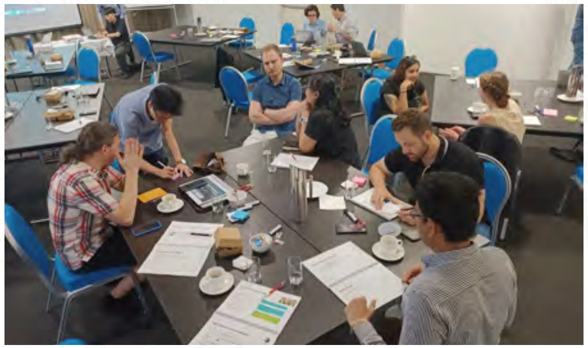
FLEET continues to proactively seek out opportunities to partner with other science and educational organisations to further the reach of Centre-relevant science, to advance equity issues and to develop future leaders.

For example, in 2022 the Centre:

- Ran a professional development workshop on teaching quantum physics to primary school teachers at STAVCON (Victorian) and CONASTA (Australian) science teachers' conferences
- Co-hosted the Gordon Godfrey Workshop, attracting more than 130 delegates with speakers from Belgium, Germany, New Zealand, Singapore, Switzerland and the USA
- Worked with veski to deliver a professional development workshop focusing on personal branding and career planning, engaging 12 STEM professionals from 11 industry organisations
- Co-hosted the inaugural inSTEM conference with nine other research organisations– a networking and career-development conference for under-represented groups in STEM; see case study p70
- Built and leveraged relationship with CSIRO STEM Professionals in Schools to increase engagement with regional and remote schools
- Worked with Deadly Science to engage and share knowledge with Indigenous students in remote communities
- Continued the transpacific colloquia series with the Joint Quantum Institute (University of Maryland) and Monash School of Physics and Astronomy, with speakers from seven US universities: Universities of Minnesota, Illinois Urbana-Champaign, Michigan, Colorado Boulder, Stony Brook University, University of California (UC) Santa Barbara and UC Berkeley; see p68
- Co-hosted research seminars with the TMOS Centre of Excellence, Monash School of Physics and Astronomy, Monash Materials Science and Engineering, and UNSW; see p68.

PROFESSIONAL COLLABORATIONS

- Delivered the fourth 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
- Chaired the committee for the 2022 National Science Quiz, working with ARC Centres of Excellence for Plant Success in Nature and Agriculture, Engineered Quantum Technology (EQUS), Exciton Science, Gravitational Wave Discovery (OzGrav), and MATRIX Mathematics Research Institute, Monash Engineering, and Defence Science Australia; see case study p72



- Engaged with Cruxes Innovation to develop ECRs' transferable skills in industry engagement, continuing the annual Idea Factory collaboration with the ARC Centre for Engineered Quantum Technology (EQUS); see case study p94.

CASE STUDY

inSTEM conference – towards a more diverse science community

New, collaborative networking event encouraging diversity and inclusion in STEM

> Participating as a member of the inSTEM Steering Committee is a great opportunity to be part of an initiative that champions inclusiveness and equity while promoting the importance of STEM within broader society. It was also important to speak on behalf of FLEET during the planning process and share the positive impacts we have made regarding STEM equity and diversity.
>
> **TENILLE IBBOTSON**
> *FLEET EO*

The inSTEM conference held in Brisbane July 2022 was a networking and career-development conference for people from marginalised or under-represented groups in STEM, and their allies.

inSTEM was organised and sponsored by a partnership of 11 science organisations, including ARC Centres of Excellence, industry transformation training centre and Defence Science Australia, recognising the many benefits to research organisations in Australia of improving diversity.

The two-day event was an opportunity for scientists to:

- Connect with others from marginalised or under-represented groups
- Develop valuable professional networks, building networking skills and strategies supporting personal career development
- Discuss strategies to improve Australia's scientific diversity, increasing access, retention and success for diverse groups.

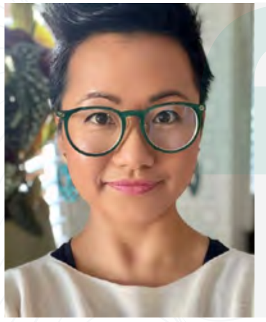
FLEET participation included nine delegates attending in-person and five attending virtually.

"It was also great to see three former FLEET Honours students attending who have moved on to applying their science skills elsewhere," says FLEET COO Dr Tich-Lam Nguyen, who shared her own experiences of transitioning from academia to research management on a panel investigating careers outside academia.

"That is, Coco Kennedy now working as a microfabrication specialist with Defence Science Australia, while Niken Priscilla and Kyla Rutherford are now pursuing their PhDs with the TMOS and Exciton Science Centres of Excellence."

inSTEM illustrates increased recognition in the science community that diversity extends beyond equal representation of women in STEM. A wider definition also includes under-represented groups in race, religion, culture, sexuality and gender identity, as also illustrated by FLEET's Diversity fellowships and scholarships.

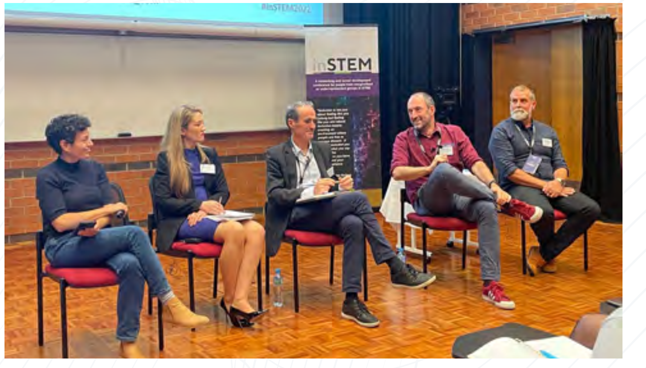
> inSTEM was a wonderful learning and networking experience. I have gained excellent professional training and insights into diversity and equity issues in STEM, and made connections with people I would not have met if not for this workshop.
>
> **YIK KHENG LEE (RMIT)**
> *FLEET attendee*



> Research has shown that diverse teams are smarter and produce better outcomes. People can only contribute their best when they feel that they are supported and respected and their contributions valued, regardless of their cultural, social-economic backgrounds, personal identity or beliefs. By creating equity in STEM, we are making the most of available grey matter and driving technological innovation and economic growth.
>
> **DR TICH-LAM NGUYEN**
> *FLEET COO*

FLEET EO Tenille Ibbotson and FLEET student Maedehsadat Mousavi were on the inSTEM steering and planning committees, working alongside representatives of the 10 other organisations.

Joining Tenille and Maedehsadat on the committee were representatives from EQUS, Defence Science Australia, ASTRO 3D, Centre for Quantum Computing, Climate Extremes, Australian Cobotics, Centre for Peptides and Protein Science, Exciton Science, OzGrav and TMOS.



FLEET representatives at inSTEM

More at FLEET.org.au/instem

CASE STUDY

National Science Quiz

A collaboration of research centres ensures a sustainable future for this valuable science outreach event

The return of the annual National Science Quiz to a public format in 2022 also represented a major project in terms of coordinating multiple research organisations (eight in total) and an innovative application of COE legacy and sustainability in outreach.

Over 200 in-person audience members and more than 400 online contestants competed in the 2022 National Science Quiz, with over 1000 watching online. The Quiz was co-presented by FLEET with a collaboration of other Centres of Excellence and other research organisations.

The National Science Quiz features a panel of scientists applying humour and scientific reasoning to answer a series of diverse, thought-provoking science questions.

FLEET's Dr Jason Major chaired the 2022 organising committee, with FLEET PhD students Josh Gray and Abigail Goff volunteering for the operational committee and on the night, gaining useful on-the-ground experience in organising and running public science outreach events.

The goal behind the multi-organisational team is that the Quiz becomes an ongoing, annual feature of the National Science Week program – beyond the terms of the individual science organisations that host it.

The Quiz was initially (from 2016 to 2021) run in Australia by the Centre for Mathematical and Statistical Frontiers (ACEMS), which coordinated co-sponsors such as FLEET and other ARC centres.

From 2022 onwards, with ACEMS having finished its funding term, the baton passed from ACEMS to FLEET. However, this was just the first step in the process to ensure the longevity of this valuable asset.

As convenor of the 2022 National Science Quiz Steering Committee, FLEET assembled a new, diverse team of partners and sponsor organisations

This is a new model for ongoing outreach events among ARC Centres. It means the great work done by ACEMS over the last six years will continue – and the groundwork that has been laid so far will ensure it continues beyond FLEET's tenure too.

DR JASON MAJOR
FLEET outreach coordinator

and continued the principle of rolling responsibility for convenors.

As centres mature through their lifecycle (seven years for an ARC Centre of Excellence), this approach should provide adequate opportunity for centres to develop their involvement in the National Science Quiz, take the lead and then pass the baton on to other centres.

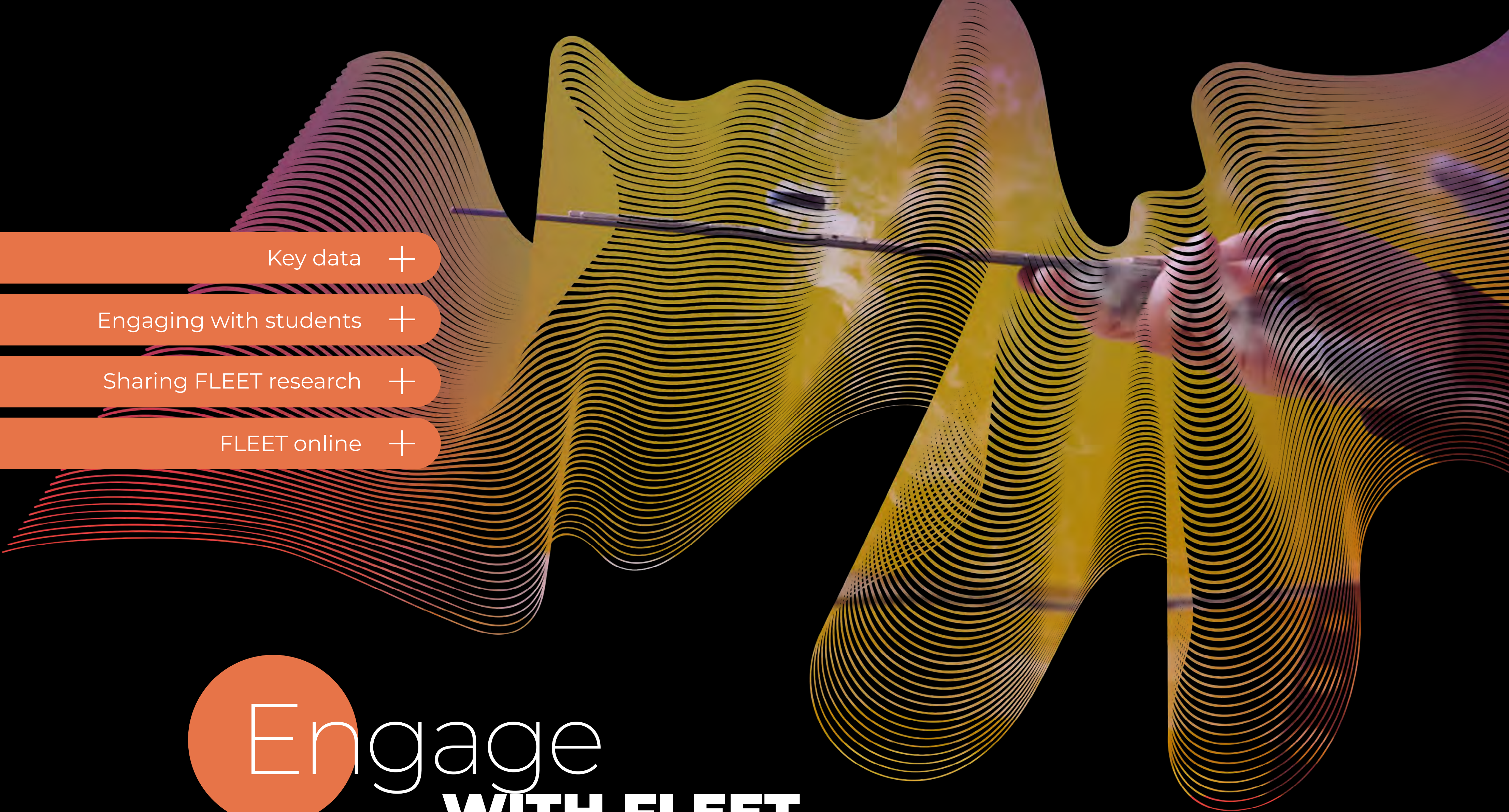
National Science Quiz committee members are typically outreach and communications officers, and researchers at each of the partner organisations.

As well as ensuring adequate funding, this provides a usefully diverse science focus among participating centres – including physics, chemistry, agriculture and maths. Individuals on the committee bring skills in outreach, communication, publicity, live events and TV.

The 2022 National Science Quiz was organised by the ARC Centres of Excellence for Plant Success in Nature and Agriculture, Engineered Quantum Technology (EQUS), Exciton Science, Gravitational Wave Discovery (OzGrav), and FLEET, MATRIX Mathematics Research Institute, Monash Engineering, and Defence Science Australia.

2022 marked the return of the Quiz to a live-audience format after two years of pandemic-enforced online participation.

More at FLEET.org.au/NSQ2022



Engage WITH FLEET

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

926
FACEBOOK FOLLOWERS
NEW 204

1608
TWITTER FOLLOWERS
NEW 196

1455
LINKEDIN FOLLOWERS
NEW 375

43,747
VIEWS OF FLEET YOUTUBE CHANNEL IN 2022

PARTNER/NODE NEWS STORIES
15

9540
AVERAGE MONTHLY UNIQUE PAGE VIEWS

NON PEER REVIEWED ARTICLES
26

PRESS RELEASES
17

MENTIONS IN ONLINE MEDIA
266

PRINT ARTICLES
17

RADIO INTERVIEWS
1

5580
AVERAGE MONTHLY NEW USERS VISIT FLEET.ORG.AU

E-NEWSLETTERS
6

FLEET outreach

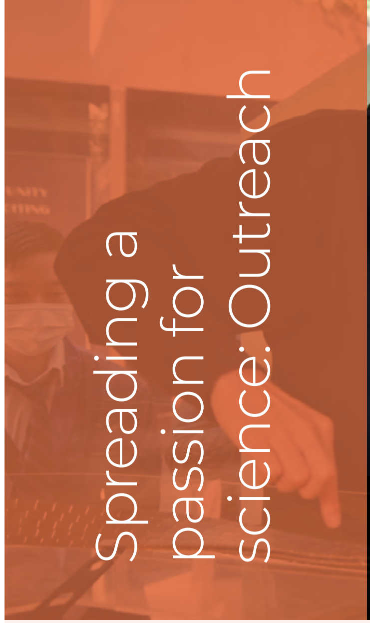
139
OUTREACH ACTIVITIES INVOLVING FLEET MEMBERS

4306
PUBLIC AUDIENCE REACHED THROUGH OUTREACH ACTIVITIES

863
HOURS SPENT ON OUTREACH

196
SCHOOL TEACHERS ENGAGED

2739
SCHOOL STUDENTS REACHED THROUGH OUTREACH ACTIVITIES



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 understanding, passion and appreciation for science in the general public
- Improving the outreach skills of FLEET members
- Facilitating public discussion of FLEET-specific research.

FLEET has an innovative and ambitious approach to outreach, with all FLEET members (from PhD student to director) required to do at least 20 hours of outreach each year. Members value outreach, seeing it as excellent training in science communications and a competitive advantage for their CVs.

FLEET's outreach program also develops members' transferable skills, as they hone their pitch and communication skills on students or the public and later apply the same skills in conversations with future collaborators or decision-makers.

> This year saw a triumphant return to face-to-face outreach for FLEET, with over 7000 students, teachers and members of the public reached. At the same time, rigorous evaluation of FLEET impact confirmed the impact of Centre efforts on scientific literacy, critical thinking and public awareness, and an increased interest in physics expressed by female school students.
>
> **DR JULE KAREL**
> *FLEET Outreach Committee Chair*

RESTARTING FACE-TO-FACE OUTREACH

After two years of severely-limited public outreach, 2022 saw FLEET hit the ground running, getting back out at public events and schools.

FLEET conducted a series of workshops with primary and lower secondary schools in Melbourne and regional Victoria, with positive impacts on students' scientific literacy and critical thinking about FLEET research.

Early evaluation of a new Centre workshop introducing primary students to novel quantum physics content suggests primary students can learn and conceptualise quantum physics. To the best of our knowledge, this is the first time this quantum physics has been introduced to Australian primary students.

FLEET got back to face-to-face teaching of its Future Electronics unit with the John Monash Science School. This unit continues to have a positive impact on students' understanding of the breadth and depth of the physics discipline, their consideration of physics as a career or subject to pursue at higher levels, and female students' greater awareness of women in physics, and thus a possible physics career for themselves.

FLEET members got involved in CSIRO's STEM Professionals in Schools program and worked with teachers in remote and regional schools to conduct workshops, develop lesson plans and talk to students about their own journeys towards a career in physics.

FLEET also participated in the Indigenous-focused Deadly Science program, chatting to students in

Interaction with practicing female scientists within FLEET's Future Electronics unit (John Monash Science School) raises students' awareness of women in physics, and thus a possible physics career for female students.

remote and Indigenous communities about FLEET research and what is happening in their school and community.

Many members of the general public were reached in 2022 through two substantial public events: Melbourne Knowledge Week and the Sydney Science Trail.

Evaluation at each activity indicated we successfully increased public awareness of FLEET research, and helped people think critically about FLEET's research problem and society's use of digital technologies.

The new FLEET Schools web resource – which aims to improve teacher and student access to FLEET's teacher- and student-based resources – saw an increase in usage. We saw significant jumps in visitation to upgraded home science activities that were re-developed for use in the classroom. FLEET.org.au/schools remains the 'go to' page of all FLEET outreach resources to schools.

FLEET's 'Ask the physicists' Facebook page (introduced in 2021) continues as a platform to

engage the primary and secondary education community, now reaching 182 followers. The focus of the page has shifted away from answering questions about physics towards being a platform to inform and update our audience on what FLEET outreach is doing, promote any new FLEET teacher or student resources and notify followers of relevant physics education news.

2022 HIGHLIGHTS

- Developing and testing new evaluation methods to rigorously assess the impact of outreach activities
- Confirming via evaluation FLEET's positive impact on student scientific literacy and critical thinking about research
- Successfully taking quantum physics into primary schools, showing that primary students can learn and conceptualise quantum physics
- Increasing public awareness of FLEET research, and understanding about society's use of digital technology, at major public events
- Broadening students' understanding of the breadth and depth of the physics discipline and giving female students a greater sense of a possible future career in physics.

FLEET will:

LEGACY

- Promote science literacy in schools
- Improve public awareness of quantum science, electronics and sustainable computing.

IN 2023 FLEET WILL

- Take the JMSS Future Electronics unit in whole or part to one other school
- Continue participating in the CSIRO STEM Professional in School program
- Co-develop at least one student workshop with Monash Tech School
- Complete FLEET's third teacher resource and continue to refine and update the content of the other resources
- Continue developing and refining methods to rigorously evaluate the impact of FLEET outreach.

OUTREACH WITH IMPACT: EVALUATING THE IMPACT OF FLEET'S OUTREACH ACTIVITIES

FLEET's public and schools outreach activities seek to promote public awareness and understanding of FLEET science, and raise awareness and understanding of FLEET (and adjacent) areas of research among students and teachers.

But how do we know if we are achieving our objective? What impact are we achieving on awareness and scientific literacy in our target audiences?

Evaluation is built into FLEET outreach: each outreach event is designed from the outset to allow evaluation, assessment and measurement against Centre goals.

> The body of data we built in 2022 has confirmed that FLEET is having a positive impact on student literacy and critical thinking about FLEET research. This is certainly gratifying to realise! But also insightful for me, as I realised how unaware students and the public are of the rise of energy consumption of digital technologies, and the implications this has for society. I feel even more strongly now that what we are doing has significant importance, and it is nice to know we have evidence to support that we are making a difference.
>
> **DR JASON MAJOR**
> *FLEET Outreach Coordinator*

2022 was the first year that we had the opportunity to rigorously evaluate FLEET's primary and secondary school workshops. Analysis of pre- and post-training evaluation data shows that our workshops, across all the year levels we engaged with, positively affected student scientific literacy and their ability to think critically about FLEET research and society's use of digital technology.

FLEET will make its outreach impact evaluation methodology available to other Centres of Excellence as part of the Centre's intention that its legacy includes improving the operation of all COEs.

Major evaluation projects in 2022 assessed outreach activities Melbourne Knowledge Week, Sydney Science Fair, Hughesdale Primary School and regional schools as well as the new pilot quantum primary schools unit.

CASE STUDY

Rural schools' outreach

In 2022 FLEET extended outreach activities to a number of regional and remote schools. Such schools have limited opportunities to engage with visiting scientists, or participate with them in hands-on science workshops.

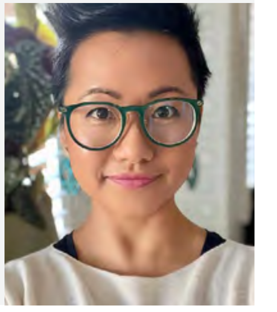
Engagement with working scientists and hands-on exercises help engage students' curiosity. Such activities expose them to the great breadth and depth of career opportunities in STEM and gives them a deeper understanding of what real scientists do.

"Regional and remote students get limited opportunities for such engagement," says FLEET outreach coordinator Dr Jason Major.

Jason, with Centre volunteers Dr Ivan Herrera Benzaquen (Swinburne) and Dr Tich-Lam Nguyen (Operations Team), engaged these rural future scientists' brains and hands with experimental and problem-solving skills, and discussed FLEET science and their own journeys to a career in science.

FLEET visited three schools in western Victoria, conducting hands-on workshops with primary students at Great Western and Moyston Primary Schools and with Year 7 students at Horsham College, plus a careers workshop with Year 11 physics students from Horsham College.

> It was really inspiring to see the teachers' enthusiasm for bringing new activities into the classroom and how keen they are in finding new ways to motivate their students.
>
> **DR TICH-LAM NGUYEN**
> *FLEET volunteer, rural schools outreach*



The 260 budding scientists from the primary and Year 7 levels got hands-on, building catapults and balloon rockets to explore Newton's second and third laws, constructing model atoms and electronic circuits, and learning a little about FLEET's research to develop low-energy electronics.

"Our evaluation showed the students enjoyed the experience," says Jason.

> When I think of physicists I think of people involved in the research and development of new technologies and the discovery of new concepts.
>
> When I think of what physicists do I believe they are trying to make new leading-edge things that can help shape the future.
>
> **HORSHAM COLLEGE YEAR 11 STUDENTS**
> *Rural school outreach*

More importantly, there was a positive impact on student literacy and critical thinking about the science that underpinned each workshop.

FLEET's evaluation showed a definitive shift in student understanding and learning about the physics concepts. Afterwards students could effectively recall and think critically about FLEET's research problem of increasing energy consumption of digital technologies and the implications of that for society.

After the careers talk with Year 11 physics students, students' perceptions of physics had changed, as had the value they placed on physics and physicists.

FLEET presented an overview of FLEET research and gave students a virtual tour of FLEET labs before conducting mock interviews with Ivan and another FLEET member (PhD candidate Karen Bayros) who joined the session online via Zoom.

Pre-evaluation indicated that students had a simple, abstract picture of physicists working to understand how the universe worked. Prior to the careers talk, there was no understanding of the integral relationship between physicists (and physics) and society and the technologies society relies on, or might rely on in the future.

After engagement, students gained a greater understanding of the discipline of physics: what it is, the breadth and depth of the discipline, and its role in society. Students became more aware that physics is not an abstract field of research but has real-world applications and implications for themselves and society, and that physicists develop actual technologies to solve problems, improve society and shape humanity's future.

In early 2023, FLEET researchers joined partner organisation the MacDiarmid Institute in schools' outreach in and around Rotorua (NZ), again reaching schools that have rarely if ever hosted visiting scientists, as well as schools with a high proportion of indigenous (Māori) students and teaching frameworks. This will be an opportunity for FLEET to learn from another international research centre on outreach to indigenous and rural communities.

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.

Centres of Excellence have the potential to make lasting, big-picture changes in Australian science policy. In 2022 FLEET put this into practice, making formal submissions to government policy on Australia's critical technologies list and Australia's quantum strategy.

In addition, seven Centre members were introduced to policymakers and policymaking via Science and Technology Australia's (STA's) Science Meets Parliament event, including meetings with individual MPs.

In early 2023, FLEET will run training for senior and early-career investigators to develop skills in having more-effective input into science policy.

COMMUNICATIONS SELF-SUFFICIENCY

While our members are in a Centre of Excellence, they have access to a communications coordinator who can help them share their research. But this will probably not be the case for most of a scientist's career. Therefore individuals should develop sufficient skills in communicating their research to be able to do this for themselves, without the aid of a full-time comms professional.

At FLEET, we are striving to develop the communications skills of our members, giving them the skills to share their research through several channels, including effectively leveraging university communications teams, online scientific platforms and social media.

Work towards this goal in 2022 included 'do it yourself' communications training for ECRs by Centre communications coordinator Errol Hunt aimed at encouraging members to write up and publicise their own scientific papers online on high-traffic platforms.

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).

In addition to the intranet, annual reports and the regular newsletter, all new members receive welcome emails outlining necessary Centre functions, logins and tools. Additionally, all-Centre meetings are used to keep members up to date with strategic goals, Centre processes and support mechanisms.

The Centre's monthly newsletter reaches all 250 members and partners, with an edited version going to another 220 external affiliates, followers and stakeholders. The newsletter achieves an open rate of approximately 50% among members, with 79% of members saying they find it useful.

Balancing the need to maintain Centre cohesion with some members' concerns about covid and other members' family commitments, FLEET's return to in-person meetings in 2022 has been accompanied by ongoing parallel support for online attendees.

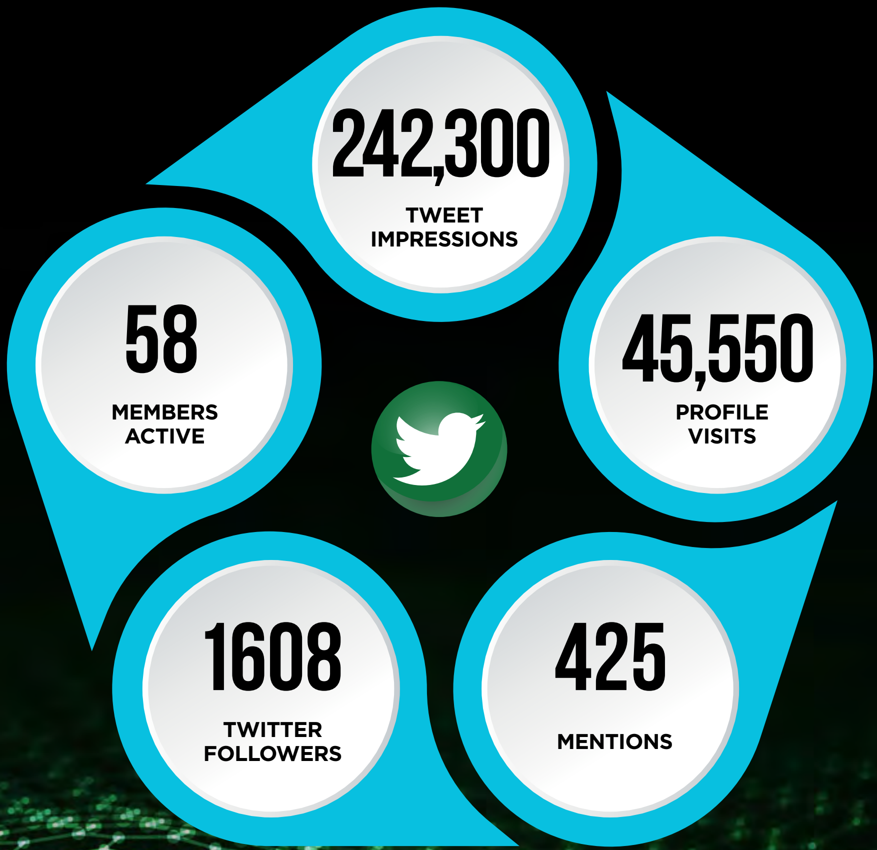
2022 HIGHLIGHTS

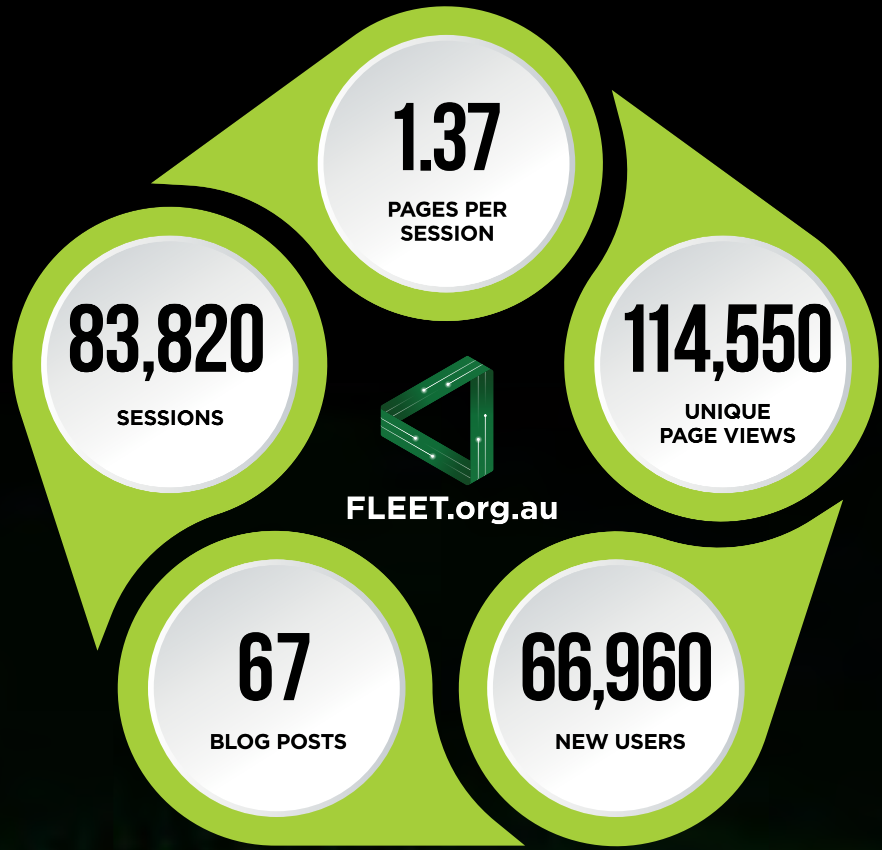
- Returning to large face-to-face Centre events, including the ICPS Satellite Symposium and annual workshop in Wollongong and Strategic Meeting in December
- Running the first iteration of 'do it yourself' communications training, helping FLEET ECRs become self-sufficient in terms of publicising their research
- Preparing Centre policy submissions on Australian's critical technologies and Australia's quantum strategy
- Supporting focus on research translation (see FLEET Translation Program, p26)
- Publishing 26 non-peer-reviewed articles, improving members' writing skills.

FLEET will:

- Improve public awareness of quantum science, electronics and sustainable computing
- Establish strong, lasting links between Australian and international science communities
- Develop the communication skills of Australia's next generation of science leaders
- Improve public perception of diversity in science.

FLEET online



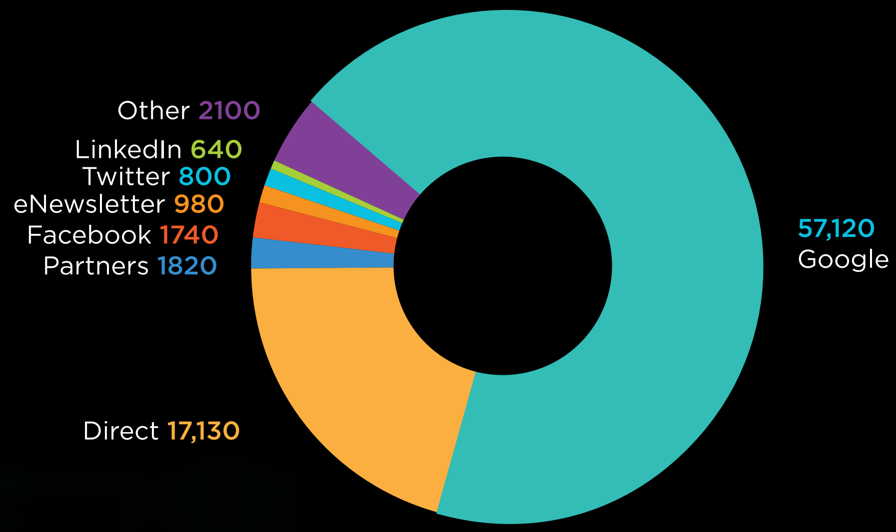


926
FOLLOWERS FLEET FACEBOOK PAGE

6980
PEOPLE REACHED 28-DAY AVG.

1200
PEOPLE WHO ENGAGED WITH OUR POSTS

42,740
PEOPLE WHO SAW OUR POSTS



1504
PAGE VISITS

1455
FOLLOWERS

127,880
POST VIEWS

Education & training

FLEET is developing future Australian science leaders and preparing them for future success

Education and Training commitments

4
RESEARCH WORKSHOPS & CONFERENCES ORGANISED

8
RESEARCH AND PROFESSIONAL DEVELOPMENT WORKSHOPS

1273
CUMULATIVE NUMBER OF CENTRE MEMBERS ATTENDING TRAINING WORKSHOPS

393
CUMULATIVE NUMBER OF NON-CENTRE MEMBERS ATTENDING TRAINING WORKSHOPS

MENTORING PROGRAMS
4

MENTORING RELATIONSHIPS
76

MENTEES
57

MENTORS
58

% WOMEN HDRs AND ECRs IN FLEET HAVING A MENTOR
56%

MENTORING QUALITY SCORE OUT OF 5 STARS - INDUSTRY AVERAGE IS 4.2
4.9

Building future science leaders

FLEET is working to develop Australia's next generation of science leaders

All FLEET's students and young researchers receive excellent supervision, are offered world-class training and other opportunities for professional development, and are supported in navigating diverse future career pathways.

The Centre currently supports **63 higher degree by research (HDR) students** and **52 postdoctoral researchers**.

PhD students are given the opportunity to have an associate supervisor from one of the other FLEET nodes, which helps with cross pollination of ideas and development of collaborative projects.

FLEET training in 2022 featured an increased focus on research translation, including seminars on intellectual property and translation by FLEET Translation Program Manager Michael Harvey, and expanded 'translation ecosystem' content in the EQUS–FLEET Idea Factory.

The ongoing FLEET research seminar series (see Collaboration, p68) was tweaked in 2022 towards presenting ECR research, thereby developing members' skills and confidence in presenting to a public group.

STRATEGIC PRIORITIES

- Develop world-class training and mentoring programs
- Establish Centre succession planning (see FLEET.org.au/strategic-plan p25)
- 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.

In addition FLEET members logged over 800 hours of science outreach, which has been confirmed to be valuable training for communicating science concepts to a wider audience.

FLEET members took the initiative to pursue their own external training on equity issues (a requirement for all Centre members), for example, learning about Aboriginal/First Peoples' cultural issues, gender and queer issues, appropriate workplace behaviour and fair interviewing practices.

In addition, members sought out external training on occupational health and safety, start-ups, career skills, supervision and leadership.

FLEET TRAINING PROGRAMS IN 2022

Training was delivered in specific fields of physics and materials science (via research seminars and colloquia) and in transferable skills such as intellectual property law and career planning, including the following:

- 8 FLEET seminars
- 4 joint seminars
- 2 research translation seminars
- 4 intellectual property seminars
- 8 US–Australia Transpacific Colloquia
- Idea Factory: 14 FLEET members
- Science Meets Parliament: 7 FLEET members
- veski Kickstart program on industry engagement (Centre meeting at Wollongong): 73 members
- InSTEM conference on equity and diversity: 17 members and alums (see case study p70)
- DIY communications' training for scientists in publicising their own research (Centre ECR workshop)
- Presenting your research: creating great figures and presentations (Centre ECR workshop)
- Cruxes Innovation Base research translation program: 2 members
- Weizmann Institute quantum Hall and topology course: 3 members.

2022 HIGHLIGHTS

- Developing translation knowledge in the EQUS–FLEET Idea Factory
- Building members' awareness of the translation ecosystem and intellectual property laws
- Introducing another seven Centre members to policymakers and policymaking via STA's Science Meets Parliament
- Running 31 professional development training events for FLEET members and affiliates.

IN 2023 FLEET WILL

In 2023 FLEET will maintain its existing level of training and research seminars and will also:

- Develop a training workshop on responsible innovation
- Reopen ECR grants in two grant rounds per year (offering a total of $20,000 per year with up to $5000 per person)
- Begin evaluating the progress of FLEET's education and training activities towards the strategic goal of developing the next generation of science leaders.

Mentor statistics	Number of members	Participation %
Chief investigators	19	90%
Partner investigators	3	12%
Associate investigators	20	53%
Research fellows	24	46%
HDR students	26	43%
Alumni and external collaborators	12	-
Total number of members	**92**	**46%**

FLEET will:

- Develop Australia's next generation of science leaders
- Train researchers in the electronics of tomorrow.

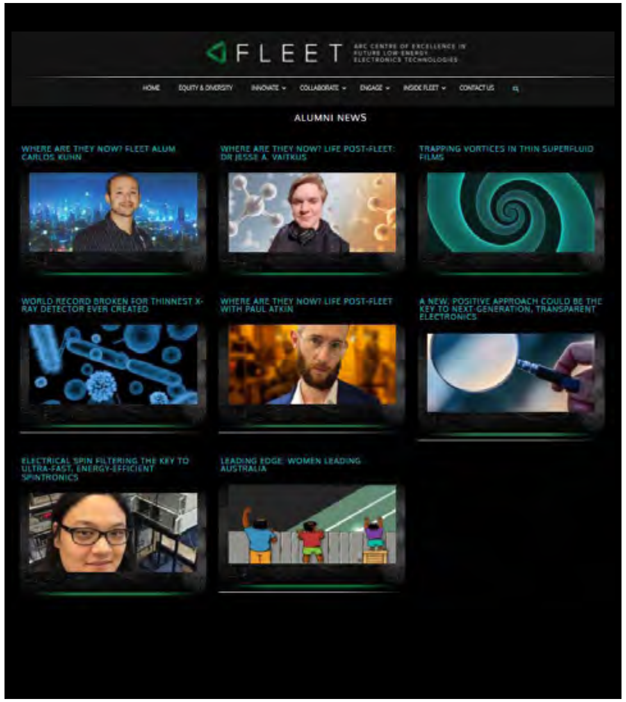
Lasting impact: FLEET alums

Members who have moved on to great new careers leverage skills developed at FLEET

Ultimately it will be FLEET's alums as much as its research outputs that define the success of the Centre.

One of the most lasting and valuable legacies left by any Centre of Excellence is its people, and five years into the life of the Centre, FLEET is seeing more and more alums move on to great careers in diverse areas.

We are extremely proud of our alums, and for both personal and professional reasons, FLEET works hard to maintain contacts – sharing alums' stories with current members and keeping alums connected via Centre communications and invitations to training and social events.



STAYING IN TOUCH

It is a testament to the sense of belonging at FLEET that almost all departing members choose to remain on the FLEET monthly newsletter list to stay in touch with the Centre.

FLEET alums updates and career highlights are included in the Centre newsletter while research blog profiles show how our alums are applying their scientific and transferable skills in different areas, helping our current PhD candidates envision more diverse future careers for themselves.

Alums under the spotlight in 2022 included:

- **Charlotte Hurry** Business Manager, ARC Centre
- **Sam Bladwell** Science editor at Nature Publishing
- **Elizabeth Marcellina** University of Sydney Research Fellow
- **Pavel Kolesnichenko** Spectroscopy postdoc, Heidelberg University Germany
- **Shilpa Sanwlani** Senior Data Analyst Financial sector crime detection
- **Jesse Vaitkus** German commercial quantum software company
- **Carlos Kuhn** Government and defence policy and consultancy.

More at FLEET.org.au/alumni

MENTORING PROGRAM

FLEET provides mentoring to personnel across all career stages (such as PhD students and early- and mid-career researchers) covering areas such as induction, career advancement and planning, equity and diversity, professional development, entrepreneurship and research leadership skills.

Three main mentoring mode are available to FLEET members within the Centre:

- Participation in FLEET governance committees
- Group mentoring via training sessions, for example, on manuscript preparation, grant writing, scientific presentation and research leadership
- Individual, goal-oriented mentoring, where members are individually matched to a mentor within FLEET (or in some cases outside FLEET) based on their needs, for example, guiding applications for promotion, grant writing or providing career advice.

There are now 87 participants and 76 active mentorship pairs (close to doubling since 2021). In addition, some FLEET members are also involved in other mentoring programs such as IMNIS and those facilitated by their local universities.

In 2022, the focus of the FLEET mentoring program was to improve participation of investigators and postdocs internally, as well as tapping into the Centre's alumni network and engaging external collaborators.

Currently, 43% of HDR students, 46% of research fellows, 53% of associate investigators and 90% of chief investigators are participating as either mentors or mentees (or both) in the FLEET mentoring program. Almost 60% of women in FLEET have mentors.

Four tailored, individual mentoring programs are available:

- For early-career researchers exploring career options
- In industry, for researchers considering work outside academia
- In academia, for researchers looking at building their academic careers
- For Women in FLEET, focusing on challenges unique to women in STEM.

FLEET's expanded mentor network includes international partners, industry representatives and alums with diverse career experiences, including from industry and research collaborators.

The commercial mentoring-management platform Mentorloop provides capacity to match mentors to mentees, and its evaluation tools measure the effectiveness of the Centre mentoring program. The platform also delivers training resources for both mentors and mentees to enhance engagement; this was added in response to member feedback.

FLEET has developed its own survey to understand the impact of the FLEET mentor program. The survey will be sent out early 2023 and again in 2024.

We are currently planning a cross-CoE mentoring program to be implemented in 2023.

Early-Career Researchers' Working Group

A working group initiated by and comprising FLEET ECRs and PhD students ensures that the Centre's training program matches the needs of its members.

The ECR Working Group ensures that the voices of students and other Centre ECRs are heard and that their needs are met, in terms of the development programs delivered within the Centre.

In 2022 the working group focused on planning and delivering training at the FLEET annual workshop (mid-2022) and three-day ECR workshop alongside the FLEET strategic meeting in December 2022. (See the case study p94).

The content of the training delivered was informed by the working group's comprehensive surveying of FLEET students and members, ensuring that the training meets the needs of FLEET students and ECRs. Other surveying has tracked translation and industry-related training needs.

The ECR Working Group has developed an evolving membership after its initiation in 2019. In 2022, the team comprised Abigail Goff, Karen Bayros, Patjaree Aukarasereenont and Yik Kheng Lee (RMIT), Mitch Conway (Swinburne), Abhay Gupta, Dr Dan Sando and Maedehsadat Mousavi (UNSW).

Support for working group initiatives has been confirmed by the FLEET Executive Committee, which provides the ECR Working Group with $10,000 to be used for ECR- and student-organised activities supporting:

- Exchange of research ideas
- Enhancing scientific skills
- Expanding members' professional skills toolkit
- Extending professional and research networks.

The working group delivers quarterly updates to the FLEET Executive Committee on its activities.

In 2022 the group has:

- Surveyed Centre students to set training program
- Planned and delivered training on creative communication and facilitated a Q&A panel examining diverse career options at FLEET's Centre Workshop in Wollongong in July 2022
- Sourced training on communications and career skills, and run a three-day ECR writing and mental-health retreat, co-located with the FLEET strategic meeting in December 2022.

FLEET's ECRs and students also drive Centre activities and policy through their involvement in the Centre's special governance committees. This involvement in Centre governance ensures that the views and needs of these cohorts are properly integrated into Centre strategy.

CASE STUDY

Developing ideas into impact at Idea Factory 2022

Learning to work within the translation ecosyste

Early-career researchers from two Centres of Excellence gathered in Queensland in November 2022 to learn how to better translate their scientific discoveries to make an impact.

In 2022, Idea Factory focused on the participants developing a wide understanding of research translation, and the translation and commercialisation ecosystem, and on participants learning to consider the impact of their research beyond the confines of academia.

Skills developed will also be useful for participants applying for funding in the FLEET Translation Program.

> The program got me thinking about end user needs.
>
> **FLEET PARTICIPANT**
> *Idea Factory 2022*

Almost 30 participants from the ARC Centres of Excellence for Engineered Quantum Systems (EQUS) and FLEET learnt about how important it was to be solving a problem that was actually important for stakeholders and end users, rather than a problem you think they might have. Another key lesson was that the solution needed to have massive (rather than incremental) impact.

The workshop included preparing elevator ('Gaddie') pitches and testing assumptions with stakeholder interviews. Participants were asked to get in touch with potential stakeholders during the workshop, and they finished on the last day by presenting their own compelling impact story.

The workshop included plenty of opportunities to network with other participants, including at the ten-pin bowling plus pizza feast on the first night and the extravagant Thai feast at the workshop dinner.

The participants all appeared to enjoy the workshop with many expressing their opinion that it opened their eyes to how their research and skills could make a difference in the world beyond universities. Several were inspired to start preparing applications for the Centre research translation programs. We look forward to seeing the results over the next few months.

> Networking with the other workshop participants was both fun and useful … talking about my research to an audience with a different level of knowledge in my area.
>
> **FLEET PARTICIPANT**
> *Idea Factory 2022*

The program was facilitated by Jonathan Lacey and Emily Chang from Cruxes Innovation.

The Idea Factory is a joint Centre of Excellence initiative involving EQUS and FLEET to provide training and networking opportunities for early-career researchers.

Previous iterations of the workshop have included grant applications and communication (2021), entrepreneurship and research translation (2019), and pitching and presentation (2018).

CASE STUDY

Creative, targeted training delivered by ECR working group

Young researchers delivering a creative, supportive training and development program

FLEET's Early-Career Researchers' Working Group delivered training at the Centre's 2022 annual workshop in Wollongong, and strategic meeting in Melbourne.

"We are endeavouring to run professional development programs that are fun, enjoyable, and meet ECRs' needs, says working group member Abigail Goff (RMIT). "Training sessions that don't feel like a chore!"

The Wollongong program kicked off with the creative-thinking 'Does science have to be serious?' journal club, and continued with an 'Academia and beyond' panel discussion focusing on science careers within and outside of academia.

The entirety of this section of the workshop was planned, prepared and delivered by working group members.

In the 'Does science have to be series?' section chaired by Dr Dan Sando, participants discussed an IgNobel paper and presented back to the group. This activity focussed on building skills in lateral

> The program helped me to look at my own research project from a different perspective and helped me realise that my research can have an impact outside of the realm of scientific journals and academia. I'm motivated to search for more information towards this: I've created a folder on my desktop with some industry/application-driven papers that can be really useful for my research.
>
> **FLEET PARTICIPANT**
> *Idea Factory 2022*

Post-training evaluation found that 100% of participants found the 2022 Idea Factory valuable and now felt confident to communicate the value of their research to a non-technical, external audience, with almost 90% confident to initiate conversations with industry stakeholders.

More at FLEET.org.au/Idea2022

> Previously, I would have never considered starting my own company or launching a start-up, but now I can see myself considering how being an entrepreneur may have an influence on the world.
>
> **MAEDEHSADAT MOUSAVI (UNSW)**
> *FLEET PhD candidate*

learning, critical thinking, communication and reviewing and analysing scientific data.

The 'Academia and beyond' panel addressed the many possible career routes available in science, with a Q&A format. Panellists shared valuable insights and tips on caring for your mental health, networking skills, how to make yourself desirable in the workforce, how to get that first job and the differences and similarities between academia and industry roles.

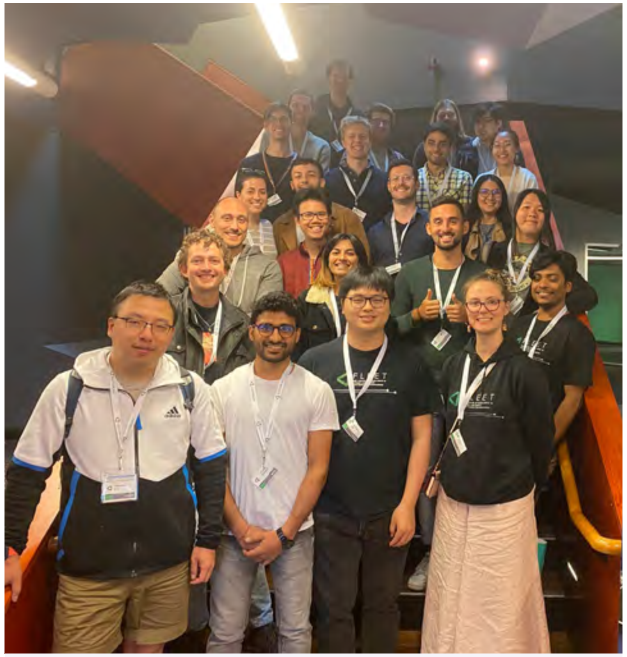
The discussion was facilitated and chaired by working group members Abigail Goff and Abhay Gupta respectively.

As part of the program, Q&A style videos were prepared by Abigail, who had sought out ten scientists and interviewed them to share their diverse career paths. These videos, edited by Abigail with Mitchell Conway, are shared on FLEET's youtube channel.

At the Centre's end-of-year strategic workshop in Melbourne, the working group coordinated training on 'DIY' communication (see p82), effective presentations, and careers.

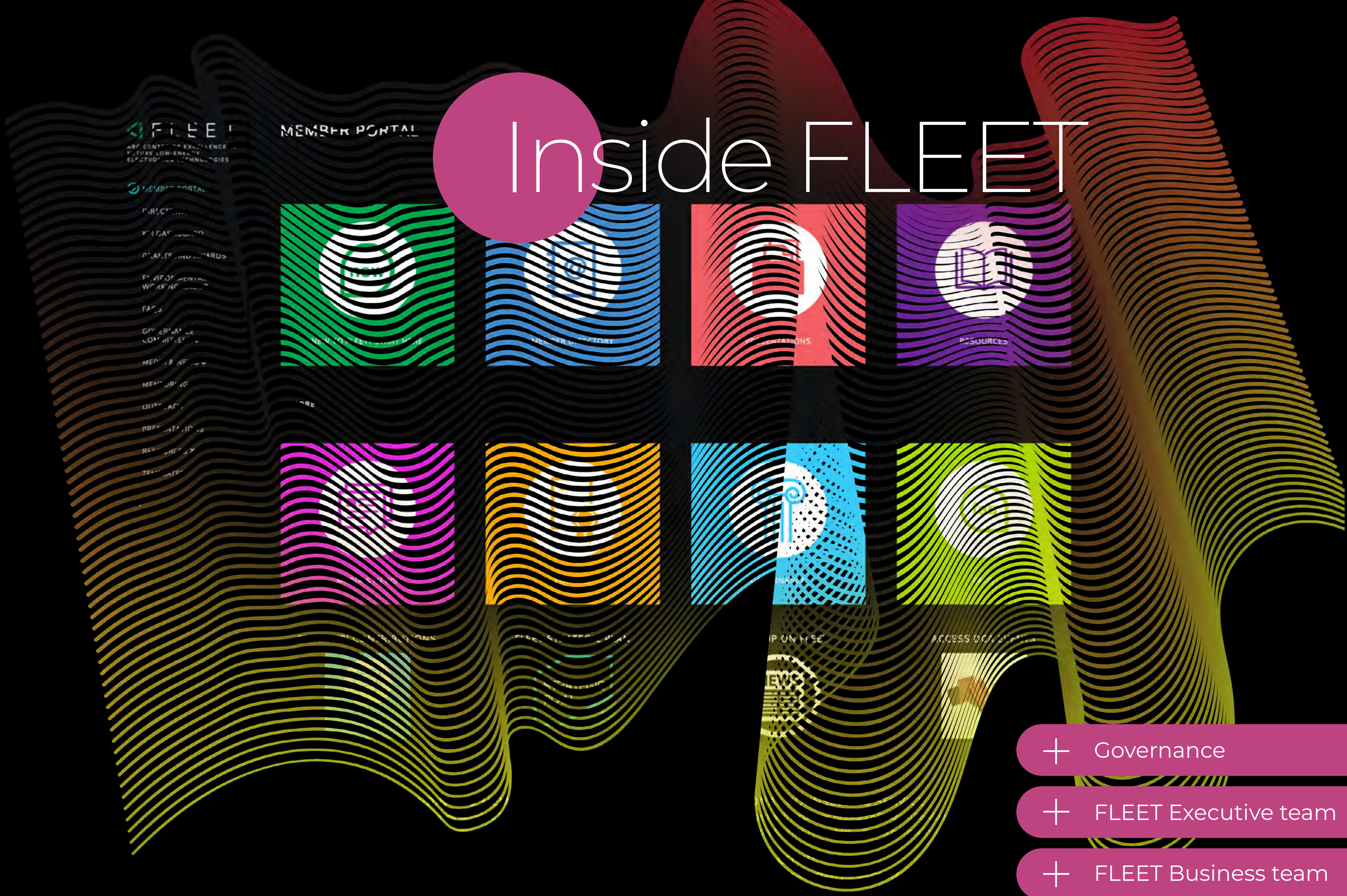
In addition, the group also creatively set up a 'wellbeing space' at the venue dedicated to networking and other health and wellbeing-related activities. The space, open for all ECRs as well as investigators attending the strategic meeting, included a quiet corner for yoga and meditation, a reading corner with bean bags and a fun corner for board games.

Members also immersed themselves in therapeutic origami folding, colouring and drawing, and accessed resources and tips on self-care and wellbeing.



FLEET students and postdocs at the ECR workshop in December 2022

Inside FLEET



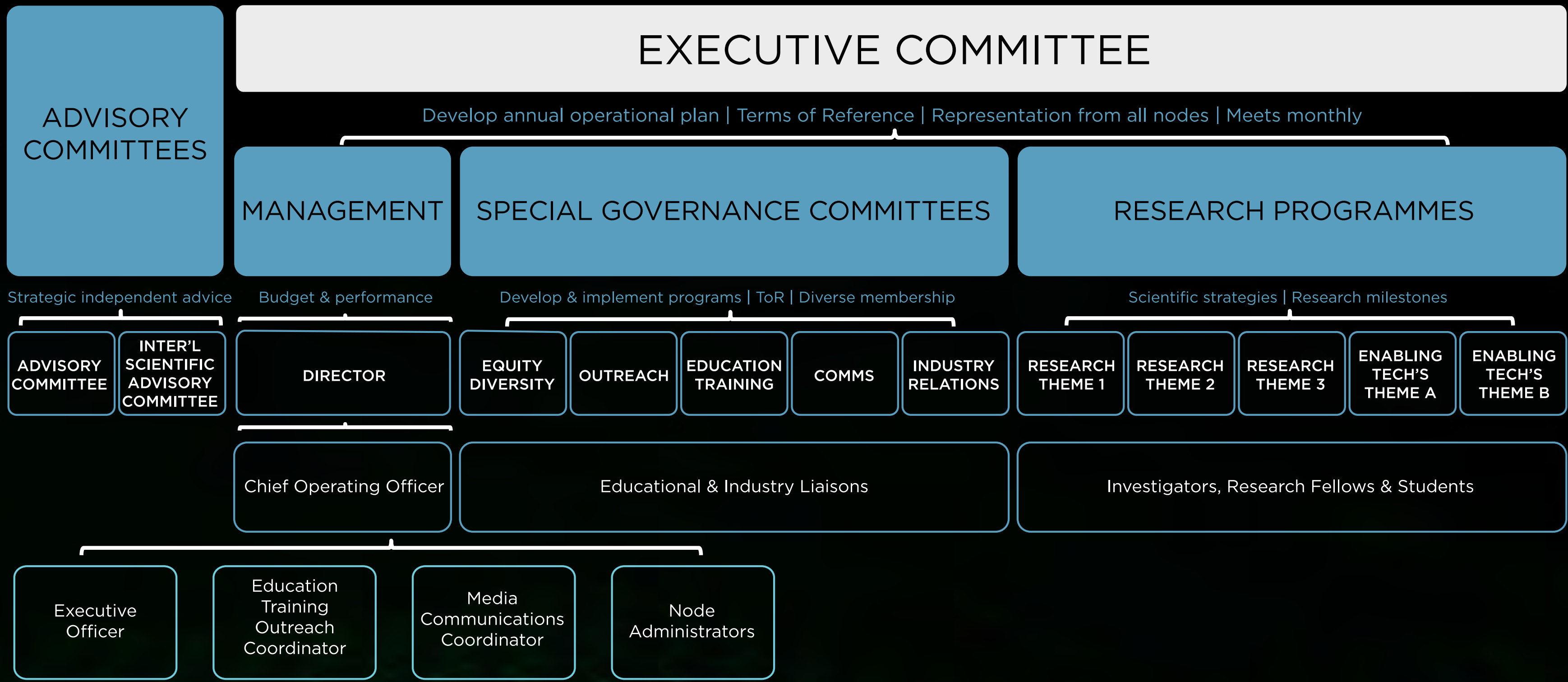
+ Governance

+ FLEET Executive team

+ FLEET Business team

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

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

Prof Francois Peeters (FLEET International Scientific Advisory Committee) at the FLEET Satellite Meeting, 2022

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
- Produces an annual report of strengths, weaknesses and opportunities.

FLEET ADVISORY COMMITTEE REFLECTIONS ON FLEET IN 2022

Meeting to reflect on FLEET's performance in 2022, the Advisory Committee first considered outcomes resulting from the list of agreed recommendations from the 2021 meeting:

- Establishment of a $500,000 translation program with six projects funded in 2022 and more being developed with guidance from the FLEET Translation Program Manager. Options to leverage other funding with industry and grants is also being explored.
- Creation of FLEET legacy platforms to celebrate research achievements as they arise beyond the Centre's operating timeline, including new 'Friends of FLEET' LinkedIn group encouraging discussion and networking beyond the formal Centre structure and into the future.
- Growth of the FLEET mentoring program with a focus on recruiting and matching external mentors, particularly from outside traditional academia to highlight other employment possibilities, using skills and knowledge gained with the Centre. Industry alumni are an important link for the success of the program.
- Planning towards internship program for students offering work experience and a perspective beyond the university environment.

Research continuity and finding inspiration for ongoing opportunities is vital for the legacy of FLEET.

DR STEVEN DUVALL
FLEET Advisory Committee

Having the capability to track alumni after their first position is a good example of legacy for FLEET.

PROF ELLEN WILLIAMS
FLEET Advisory Committee

ADVISORY COMMITTEE MEMBERS

Dr An Chen
Executive Director
Semiconductor Research Corporation, IBM, USA
Nanoelectronics Research Initiative, USA

Prof Andrew Peele
Director
Australian Synchrotron, Australia

Prof Ellen Williams
Distinguished Professor
University of Maryland, USA

FLEET Governance Committee Chairs provided updates on their activities and legacy plans, with all committees focussed on assessing programs to determine what did and didn't work so that information can be shared broadly as a learning tool. FLEET can guide new Centres of Excellence to streamline their activities based on prior experience. Legacy plans were well received by the Advisory Committee and FLEET was encouraged to focus on the positive, overarching message of what the Centre has achieved.

The Centre identified the following key focus areas for 2023 and 2024:

- Retaining women ECRs
- Preparing members for their future careers via mentoring, internships and career pathways
- Continue delivering FLEET's sustainability and translation plans focusing on the sustainability of the research network beyond FLEET.

The Advisory Committee looks forward to hearing about the outcomes of the above activities and also the upcoming workshop on 'Future electronic materials research in Australia'.

Prof Joanna Batstone
Director
Monash Data Futures Institute

Prof Luigi Colombo
Fellow
Texas Instruments, USA

Prof Michael Ryan
Pro Vice-Chancellor (Research)
Monash University

Dr Steven Duvall
Silanna Semiconductor

> It's valuable to bring back alumni who are currently working in the industry to share their experiences with the current cohort.
>
> **PROF JOANNA BATSTONE**
> *FLEET Advisory Committee*

INSIDE FLEET

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
- Produces an annual report placing FLEET's progress in an international context and making recommendations for future directions.

INTERNATIONAL SCIENTIFIC ADVISORY COMMITTEE MEMBERS

Prof Ali Yazdani
Professor of Physics
Princeton University, USA

Dr Esther Levy
Editor-in-Chief
Advanced Materials Technologies

Prof Francois Peeters
Professor of Physics
University of Antwerp

Prof Hidenori Takagi
Director
Max Planck Institute for Solid State Research, Germany

Sir Kostya Novoselov
Professor of Physics
University of Manchester, UK

Sir Michael Pepper
Professor of Physics
University College London, UK

Prof Wolfgang Ketterle
Professor of Physics
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

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

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

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.

EXECUTIVE COMMITTEE MEMBERS

Alex Hamilton
Deputy Director, Leader Research theme 1
UNSW

Elena Ostrovskaya
Deputy Chair, Equity and Diversity Committee
Leader Research theme 2
ANU

Kris Helmerson
Leader, Research theme 3
Monash

Xiaolin Wang
Leader, Enabling technology A
UOW

Lan Wang
Leader, Enabling technology B
RMIT

Jeff Davis
Chair, Equity and Diversity
Swinburne

Julie Karel
Chair, Outreach
Monash

Karina Hudson
Chair, Communications
UNSW

Matt Davis
Director, FLEET Translation Program
UQ

Susan Coppersmith
Chair, Education and Training
UNSW

Sumeet Walia
Chair, Industry Relations
RMIT

Business team

The FLEET Business Team does a great job in trying to bring the various nodes and groups together, and communicating the work of FLEET members.

FLEET MEMBER SURVEY

Tich-Lam Nguyen

Chief Operating Officer

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

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.

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 Education and Training Coordinator

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

Cecilia Bloise

Node Administrator, UNSW

Cecilia supports FLEET operations and reporting at UNSW and provides administrative support to node leader Prof Alex Hamilton. Jan-Aug 2022

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. From Nov 2022

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.

Tatiana Tchernova

Node Administrator

Swinburne

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

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.

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

Lan Wang
Chief Investigator
RMIT

EQUITY AND DIVERSITY COMMITTEE MEMBERS

Matthew Davis
Chief Investigator
UQ

Meera Parish
Chief Investigator
Monash

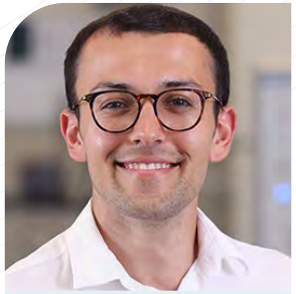
Nicci Coad
Node Administrator
RMIT

Sumeet Walia
Scientific Associate Investigator
RMIT

Tenille Ibbotson
Executive Officer
FLEET

Tich-Lam Nguyen
Chief Operating Officer
FLEET

Xiaolin Wang
Chief Investigator
UOW



Yonatan Ashlea-Alava
Research Fellow
UNSW

> Retention of women should be the focus of FLEET in the final years of the centre.
>
> **PROF MICHAEL RYAN**
> *FLEET Advisory Committee*

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

Prof Susan Coppersmith
Committee Chair
UNSW

Matthew Davis
Committee Deputy Chair
UQ

Jan Seidel
Chief Investigator
UNSW

Jared Cole
Chief Investigator
RMIT

Jason Major
Education and Outreach Coordinator
FLEET

Jeff Davis
Chief Investigator
Swinburne

EDUCATION AND TRAINING COMMITTEE MEMBERS

Jesper Levinsen
Scientific Associate Investigator
Monash

Oleh Klochan
Chief Investigator
UNSW

Peggy Qi Zhang
Research Fellow
UNSW

Xiaolin Wang
Chief Investigator
UOW

FLEET has an extensive network of experts worldwide who are affiliated with the Centre. This provides unique education opportunities for our students and researchers, where they can learn from the world's best researchers in the field.

JARED COLE
Former FLEET Education and Training Committee Chair

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 section.

OUTREACH COMMITTEE MEMBERS

Julie Karel
Committee Chair
Monash

Nikhil Medhekar
Committee Deputy Chair
Monash

Angela White
Research Fellow
UQ

Chris Vale
Chief Investigator
Swinburne

Dimi Culcer
Chief Investigator
UNSW

Eliezer Estrecho
Research Fellow
ANU

OUTREACH COMMITTEE MEMBERS

Errol Hunt
Senior Communications Coordinator
FLEET

Jason Major
Training & Outreach Coordinator
FLEET

Joshua Gray
PhD student
RMIT

Matthew Davis
Chief Investigator
UQ

Meera Parish
Chief Investigatorvz
Monash

Karina Hudson
Scientific Associate Investigator
UNSW

FLEET has excellent resources regarding outreach, and many people excited about communicating with the general public. Easy access to these resources has made outreach much more accessible than doing these things independently.

FLEET MEMBER SURVEY

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 section.

COMMUNICATIONS COMMITTEE MEMBERS

Karina Hudson
Committee Chair
UNSW

David Cortie
Committee Deputy Chair
UOW

Abigail Goff
PhD Student
RMIT

Cecilia Bloise
Node Administrator
UNSW

Chutian Wang
PhD Student
Monash

Errol Hunt
Senior Communications Coordinator
FLEET

COMMUNICATIONS COMMITTEE MEMBERS

Jackson Smith
Research Associate Investigator
RMIT

Jared Cole
Chief Investigator
RMIT

Jeff Davis
Chief Investigator
Swinburne

Matt Reeves
Associate Investigator
UQ

Matthias Wurdack
PhD Student
ANU

Nagy Valanoor
Chief Investigator
UNSW

Stuart Earl
Research Fellow
Swinburne

Vivasha Govinden
PhD Student
UNSW

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 Chair
RMIT

Torben Daeneke
Committee Deputy Chair
RMIT

Errol Hunt
Senior Communications Coordinator
FLEET

Jian-Zhen Ou
Scientific Associate Investigator
RMIT

INDUSTRY RELATIONS COMMITTEE MEMBERS

Kourosh Kalantar-zadeh
Chief Investigator
UNSW

Matthew Gebert
PhD Student
Monash

Matthias Wurdack
PhD Student
ANU

Mitchell Conway
PhD Student
Swinburne

Stuart Earl
Research Fellow
Swinburne

Tich-Lam Nguyen
Chief Operating Officer
FLEET

Xiaolin Wang
Chief Investigator
UOW

> The Industry Relations Committee leads engagement with industrial partners and establishes groundwork for ultimate translation and commercialisation of FLEET's science into affiliated industries.
>
> **KOUROSH KALANTAR-ZADEH**
> *IR Committee member*

Education and industry liaisons

FLEET works with specialised educational and outreach liaisons.

EDUCATION AND INDUSTRY LIAISONS

Dr Andrew Hind

General Manager of Molecular Spectroscopy

Agilent Technologies

Camille Thomson

Australian Institute of Policy and Science

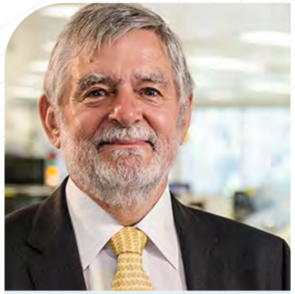
Chris Gilbey

CEO

Imagine Intelligent Materials Pty Ltd

Dr Eroia Barone-Nugent

Australian Institute of Policy and Science



Dr Jim Patrick

Chief Scientist and Senior Vice President Research and Applications

Cochlear Limited

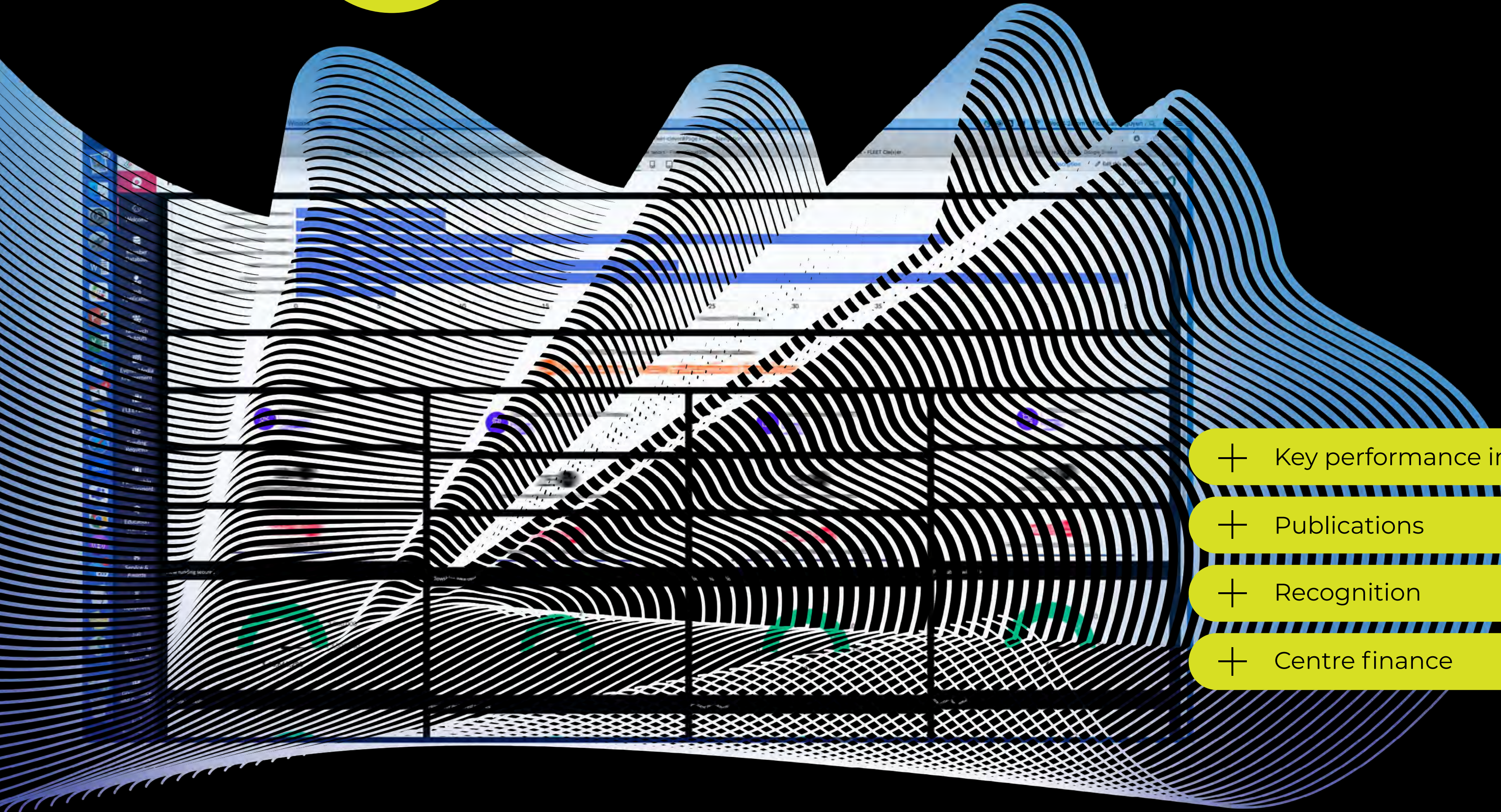
Mark Muzzin

CSIRO

Dr Toby Bell

Monash University

Performance

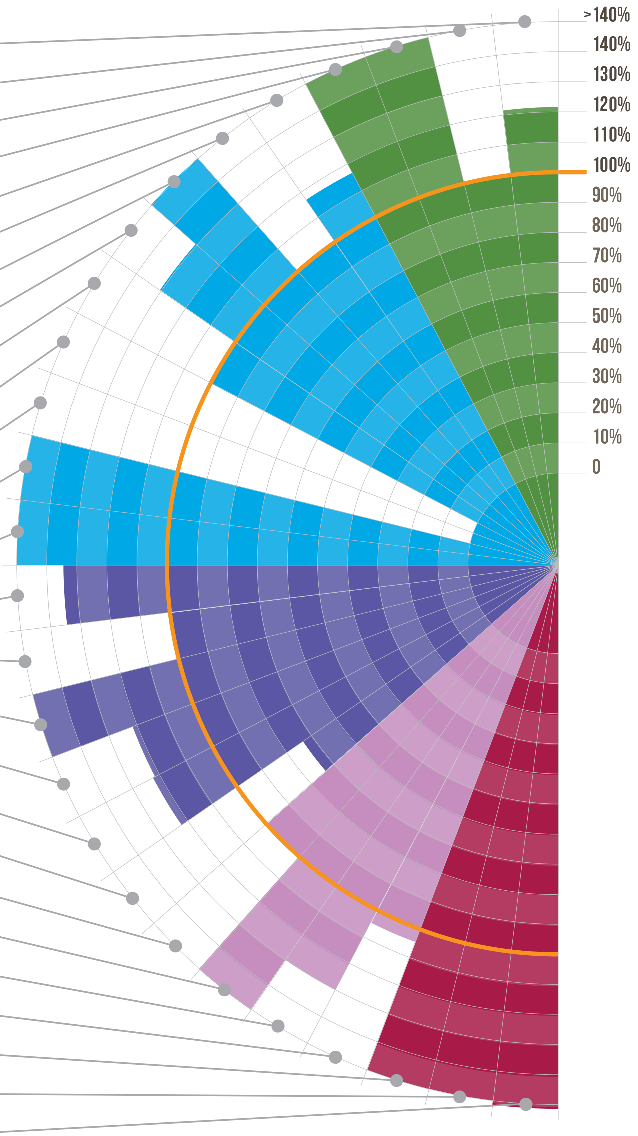


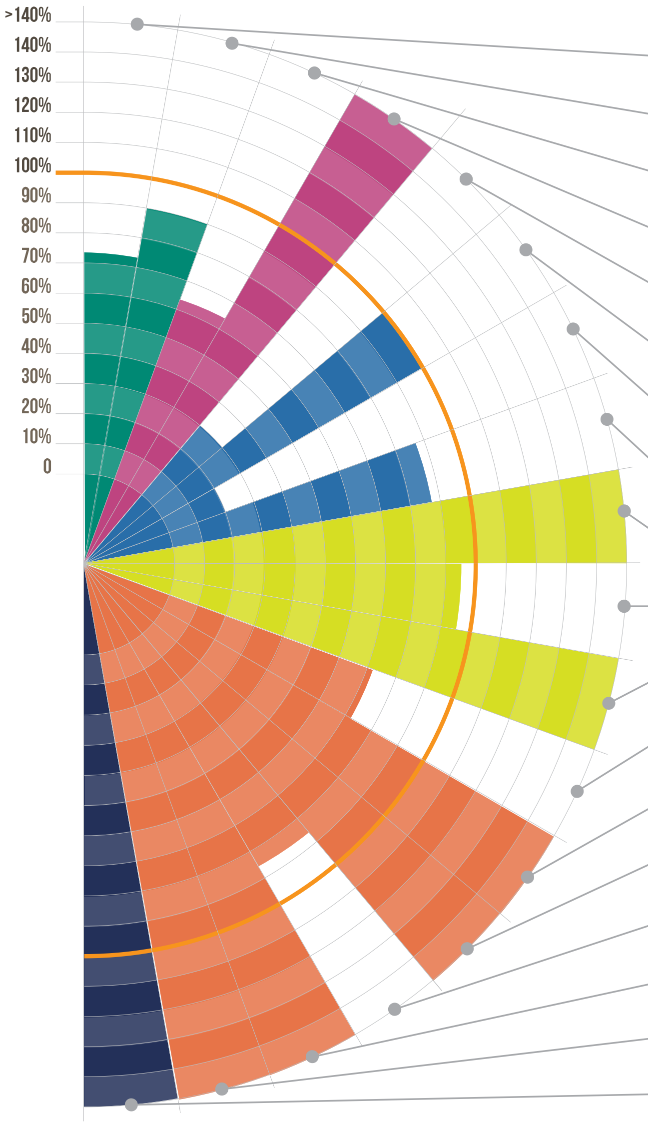
Key performance indicators

PERFORMANCE MEASURES

- Research Outputs
- Education and Training
- FLEET Research Personnel
- Mentoring
- Partnership Development

STANDARD KPI	Target	Actual	% Met
Journal articles	100	121	121%
Patents applied	2	2	100%
Technical briefings presented to targeted industry groups	1	2	>140%
Publications in journals with IF >7	20	67	>140%
Research & professional development courses	6	7	117%
Training workshops on diversity and gender equity	1	1	100%
Centre attendees at training workshops	500	1274	>140%
Non-Centre attendees at training workshops	300	393	131%
Workshops held within Australia	2	2	100%
Workshops held outside Australia	2	0	0%
National symposia & conferences facilitated	1	0	0%
International symposia & conferences facilitated	1	2	>140%
Industry engagement workshops held	1	3	>140%
Postdoctoral researchers (total FTE)	35	47	134%
Honours students (total)	5	5	100%
Masters students (total)	0	2	>140%
PhD students (total)	50	61	122%
Associate Investigators (total)	30	38	127%
PhD completions	15	11	73%*
Mentoring programs offered by the Centre	4	4	100%
Mentors within the Centre	40	58	>140%
Mentors external to the Centre	10	13	130%
FLEET members participating as mentees	55	57	104%
Organisational links in training and mentorship programs	5	27	>140%
Presentations to stakeholders	30	98	>140%
New organisations collaborating with, or involved in, the Centre	8	25	>140%





% Met	Actual	Target	CENTRE SPECIFIC KPI
73%*	22%	30%	Percentage of women HDRs in FLEET
90%*	27%	30%	Percentage of women ECRs in FLEET
63%*	25	40	Invited talks at international conferences
>140%	3	2	New fellowships awarded to CIs, ECRs and AIs
30%*	3	10	International students and ECRs visiting FLEET
100%	30	30	Senior investigators - International visitors FLEET
20%*	2	10	Chief investigators visiting partners
87%*	13	15	ECR & HDR students visiting partners
>140%	26	10	Non-peer reviewed works by FLEET members
96%	288	300	Mentions of FLEET research in the media
>140%	6072	1500	Unique hits to Centre website, monthly average
72%*	863	1200	Hours spent in outreach activities
>140%	2739	2000	Primary/secondary students reached in outreach activities
>140%	196	75	Primary/secondary teachers reached in outreach activities
86%*	4306	5000	Public reached in outreach activities
>140%	22	10	Organisational links in education and outreach programs
>140%	21	10	End-user relationships established
>140%	46,665	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 2022

STANDARD KEY PERFORMANCE INDICATORS FOR CENTRE OF EXCELLENCE				
Category	**Key Performance Indicators**	**Target 2022**	**Actual 2022**	**% Met**
Research Outputs	Journal articles	100	121	121%
	Patents applied	2	2	100%
	Technical briefings presented to targeted industry groups	1	2	>140%
	Publications in journals with IF >7	20	67	>140%
Education & Training	Research & professional development courses	6	7	117%
	Training workshops on diversity and gender equity	1	1	100%
	Centre attendees at training workshops	500	1274	>140%
	Non-Centre attendees at training workshops	300	393	131%
	Workshops held within Australia	2	2	100%
	Workshops held outside Australia	2	0	0%
	National symposia & 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	47	134%
	Honours students (total)	5	5	100%
	PhD students (total)	50	61	122%
	Masters students (total)	0	2	>140%
	Associate Investigators (total)	30	38	127%
	PhD completions	15	11	73% *
Mentoring	Mentoring programs offered by the Centre	4	4	100%
	Mentors within the Centre	40	58	>140%
	Mentors external to the Centre	10	13	130%
	FLEET members participating as mentees	55	57	104%
Partnership development	Organisational links in training and mentorship programs	5	27	>140%
Research engagement & outreach	Presentations to stakeholders	30	98	>140%
	New organisations collaborating with, or involved in, the Centre	8	25	>140%

CENTRE-SPECIFIC KEY PERFORMANCE INDICATORS FOR FLEET				
Category	**Key Performance Indicators**	**Target 2022**	**Actual 2022**	**% Met**
Gender Equity	Percentage of women HDRs in FLEET	30%	22%	73% *
	Percentage of women ECRs in FLEET	30%	27%	90% *
Recognition	Invited talks at international conferences	40	25	63% *
	New fellowships awarded to CIs, ECRs and AIs	2	3	>140%
Partnership development	International Students and ECRs visiting FLEET	10	3	30% *
	Senior investigators - International visitors to FLEET	30	30	100%
	Chief Investigators visiting partners	10	2	20% *
	ECRs & HDRs students visiting partners	15	13	87% *
FLEET PR & Marketing	Non-peer reviewed works written by FLEET members	10	26	>140%
	Mentions of FLEET research in the media	300	288	96%
	Unique hits to Centre website, monthly average	1500	6072	>140%
Outreach	Hours spent in outreach activities	1200	863	72% *
	Primary/Secondary students reached in outreach activities	2000	2739	>140%
	Primary/Secondary teachers reached in outreach activities	75	196	>140%
	Public reached in outreach activities	5000	4306	86% *
	Organisational links in education and outreach programs	10	22	>140%
	End-user relationships established	10	21	>140%
New Funding	Other research income secured by Centre staff (thousands)	3000	46,665	>140%

*** KPI targets unmet due to prolonged impact of the global pandemic: extended delays in visa processing for overseas research personnel affecting staff recruitment, PhD candidature extensions, travel and in-person meetings and events are only slowly resuming.**

FLEET Peer-reviewed publications

1. A, A.; Hou, F.; Seidel, J.; B V, R.; Sharma, P. *Microstructural and Piezoelectric Properties of ZnO Films. Materials Science in Semiconductor Processing* **2022**, 146, 106680. https://doi.org/10.1016/j.mssp.2022.106680. Impact factor less than 4 *
2. Afzal, W.; Yue, Z.; Li, Z.; Fuhrer, M.; Wang, X. *Observation of Large Intrinsic Anomalous Hall Conductivity in Polycrystalline Mn_3Sn Films. Journal of Physics and Chemistry of Solids* **2022**, 161, 110489. https://doi.org/10.1016/j.jpcs.2021.110489. Impact factor less than 4
3. Ahmed, S.; Cui, X. Y.; Murmu, P. P.; Ding, X.; Chu, X. Z.; Sathish, C. I.; Bao, N. N.; Liu, R.; Zhao, W. Y.; Kennedy, J.; Tan, T.; Peng, M.; Wang, L.; Ding, J.; Wu, T.; Wang, X. L.; Li, S.; Vinu, A.; Ringer, S. R.; Yi, J. B. *Doping and Defect Engineering Induced Extremely High Magnetization and Large Coercivity in Co Doped $MoTe_2$. Journal of Alloys and Compounds* **2022**, 918, 165750. https://doi.org/10.1016/j.jallcom.2022.165750. Impact factor 4 to 7
4. Ahmed, T.; Kuriakose, S.; Tawfik, S. A.; Mayes, E. L. H.; Mazumder, A.; Balendhran, S.; Spencer, M. J. S.; Akinwande, D.; Bhaskaran, M.; Sriram, S.; Walia, S. *Mixed Ioni-Electronic Charge Transport in Layered Black-Phosphorus for Low-Power Memory. Adv Funct Materials* **2022**, 32 (10), 2107068. https://doi.org/10.1002/adfm.202107068. Impact factor >10 *
5. Akhgar, G.; Li, Q.; Di Bernardo, I.; Trang, C. X.; Liu, C.; Zavabeti, A.; Karel, J.; Tadich, A.; Fuhrer, M. S.; Edmonds, M. T. *Formation of a Stable Surface Oxide in $MnBi_2Te_4$ Thin Films. ACS Appl. Mater. Interfaces* **2022**, 14 (4), 6102–6108. https://doi.org/10.1021/acsami.1c19089. Impact factor 7 to 10 * #
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8. Alidoosti, M.; Esfahani, D. N.; Asgari, R. *σ h Symmetry and Electron-Phonon Interaction in Two-Dimensional Crystalline Systems. Phys. Rev. B* **2022**, 106 (4), 045301. https://doi.org/10.1103/PhysRevB.106.045301. Impact factor less than 4 *
9. Alidoosti, M.; Nasr Esfahani, D.; Asgari, R. *Superconducting Properties of Doped Blue Phosphorene: Effects of Non-Adiabatic Approach. 2D Mater.* **2022**, 9 (4), 045029. https://doi.org/10.1088/2053-1583/ac9069. Impact factor 4 to 7 *
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12. Asgari, R.; Culcer, D. *Unidirectional Valley-Contrasting Photocurrent in Strained Transition Metal Dichalcogenide Monolayers. Phys. Rev. B* **2022**, 105 (19), 195418. https://doi.org/10.1103/PhysRevB.105.195418. Impact factor less than 4 *
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 # publications involving partner investigators
*** publications involving associate investigators**
Impact factor at time of publication

PERFORMANCE

Patents

FLEET MEMBERS INVOLVED	PATENT TITLE	PATENT IDENTIFICATION NUMBER	DATE FILED
Priyank Kumar	Electrolytes and electrolyte additives for aqueous rechargeable zinc batteries	2022903850	15-12-2022
Torben Daeneke, Caiden Parker	Method of synthesising nanodroplets	2022903995	23-12-2022

Awards, honours and grants

MEMBERS INVOLVED	NAME OF AWARD GRANT SCHEME	DESCRIPTION OF AWARD / GRANT	FUNDING SOURCE	GRANT ID	TOTAL AMOUNT OF FUNDING (AUD)
Nikhil Medhekar, Julie Karel	ARC Discovery Project	Metal Halide Perovskite Spin-Orbit Torque Devices. This project aims to demonstrate a new, highly efficient spin-based electronic device by developing a fundamental understanding into the generation and transport of spin in metal halide perovskite based heterostructures.	Other ARC grants	DP220103783	423,000
Joanne Etheridge	ARC Discovery Project	Imaging Symmetry – A New Mechanism for Revealing the Structure of Matter. This project aims to develop a revolutionary method for imaging atomic structures. In this method, the image contrast derives from the symmetry of the structure, measured at the picometre scale, using tiny electron probes.	Other ARC grants	DP220103800	510,000
Nagarajan Valanoor, Laurent Bellaiche	ARC Discovery Project	Ferroelectric bilayer composites with giant electromechanical properties.. This project aims to create a novel bilayer ferroelectric material structure that provides giant electromechanical response at the nano-scale.	Other ARC grants	DP220102790	465,000
Torben Daeneke	ARC Discovery Project	Liquid metal solvents and colloids – a new frontier in chemistry. This project aims to develop a holistic understanding of dynamic bond formation within molten metals to unlock the full potential of liquid metal chemistry.	Other ARC grants	DP220101923	422,000
David Cortie	ARC Discovery Project	Locally structured polar-photofunctional materials for energy conversion.	Other ARC grants	DP230100462	466,114
Elena Ostrovskaya	ARC Discovery Project	Exciton-mediated room-temperature superconductivity	Other ARC grants	DP230102603	480,966
Kourosh Kalantar-zadeh, Nicola Gaston	ARC Discovery Project	Accessing Liquid Noble Metals for Low Temperature Chemical Reactions	Other ARC grants	DP230102813	609,012
Xiaolin Wang, Kirrily Rule, Zhi Li	ARC Discovery Project	Giant magnetic-thermoelectricity in topological materials	Other ARC grants	DP230102221	420,000
Mark Edmonds	ARC Future Fellowship	Kagome metals: From Japanese basket to next generation electronic devices. This project aims to investigate a new material that is very promising for electronic devices that can operate faster, and be more energy efficient than today's silicon-based technology.	Other ARC grants	FT220100290	802,542

MEMBERS INVOLVED	NAME OF AWARD GRANT SCHEME	DESCRIPTION OF AWARD / GRANT	FUNDING SOURCE	GRANT ID	TOTAL AMOUNT OF FUNDING (AUD)
Joanne Etheridge	ARC Laureate Fellowship	"New ways to see" - Reimagining Electron Microscopy . Understanding materials at the level of individual atoms can be critical for understanding their properties. This program aims to develop new ways to measure the structure of matter at the level of atoms by reimagining the fundamental concepts behind an electron microscope.	Other ARC grants	FL220100202	3,221,432
Jan Seidel, Michael Fuhrer	ARC LIEF	Nano-IR Facility for the Search of New Multifunctional Materials. Investigations of 2D and van der Waals materials, biological samples, photovoltaic and energy materials, and quantum devices on the nano- and microscale are revolutionising medicine, communications, information technology, energy production and storage by virtue of new phenomena.	Other ARC grants	LE220100111	738,750
Dongchen Qi	ARC LIEF	Versatile Physical Property Measurement System for South-East Queensland	Other ARC grants	LE230100045	586,799
Michael Fuhrer, Mark Edmonds, Susan Coppersmith	ARC LIEF	Atomic Scale Control over Quantum Materials. This project aims to establish a state-of-the-art microscope and materials growth facility in Australia to develop functional quantum materials.	Other ARC grants	LE220100108	1,173,128
Alex Hamilton, Jared Cole, Lan Wang, Nagarajan Valanoor, Nikhil Medhekar, Feixiang Xiang, Golrokh Akhgar, Karina Hudson, Julie Karel	ARC LIEF	Facility for growth and characterisation of advanced materials and devices	Other ARC grants	LE230100065	1,310,536
Sumeet Walia	ARC LIEF	Facility for enabling low thermal budget Si/SiGe technologies. This project aims to enhance Australian micro/nano fabrication capability and strengthen research across a range of key technologies by establishing an advanced state-of-the art semiconductor facility that enables deposition of wide range of silicon-based films at low thermal budget.	Other ARC grants	LE220100095	580,000

AWARDS, HONOURS AND GRANTS

MEMBERS INVOLVED	NAME OF AWARD GRANT SCHEME	DESCRIPTION OF AWARD / GRANT	FUNDING SOURCE	GRANT ID	TOTAL AMOUNT OF FUNDING (AUD)
Jian-zhen Ou, Yuerui (Larry) Lu	ARC LIEF	Cryogenic Near-Field Imaging and Spectroscopy Facility at the 10-nm-Scale	Other ARC grants	LE230100113	970,000
Lan Wang, Xiaolin Wang, Daisy Qingwen Wang, Feixiang Xiang, Guolin Zheng, Zengji Yue	ARC LIEF	Scoping the world of ultra-thin film and ultra-high pressure environments. This proposal will establish a unique Australian research facility, a combination of high efficiency Thin Film Thermophysical Property Analyser and a complete package of tools for materials and devices fabrication and characterisation at ultra-high pressures Almax DiaCell.	Other ARC grants	LE220100085	521,816
Kourosh Kalantar-zadeh, Jian-zhen Ou	ARC LIEF	High performance chalcogenide processing addressing grand challenges.	Other ARC grants	LE230100121	500,000
Joanne Etheridge	ARC LIEF	An in-situ and multiscale scanning electron microscopy suite. This project aims to establish a purpose-build in-situ scanning electron microscope for imaging during testing macroscopic samples together with a second microscope for correlative high magnification analysis.	Other ARC grants	LE220100165	2,020,000
Matthew Davis	Australia India Strategic Research Fund	Quantum-enhanced atomic gravimetry for improved sensing capabilities	Other external funding	AIRXIV000025	1,245,000
Chris Vale	Breakthrough Victoria	Funding to establish a Asia-Pacific quantum computing and technology facility at Swinburne University of Technology known as the ColdQuanta–Swinburne Quantum Technology Centre Media Release	Other external funding		29,000,000
Liam Watson, Daniel McEwen	David Warren Philanthropic Fund	PhD top-up scholarship awarded to outstanding physics students studying 2D materials	Other external funding		60,000
Baoyue Zhang	Malcolm Moore Industry Award	Awarded to three early career researchers to support industry-partnered research projects	Industry		26,000
Qingdong Ou	Monash Engineering Dean's Award for Excellence in Research by an ECR	Award of Excellence for early career researchers	Monash University		5,000

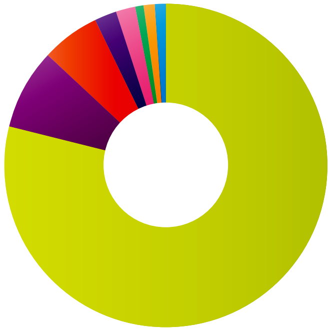
MEMBERS INVOLVED	NAME OF AWARD GRANT SCHEME	DESCRIPTION OF AWARD / GRANT	FUNDING SOURCE	GRANT ID	TOTAL AMOUNT OF FUNDING (AUD)
Qingdong Ou	Monash Engineering EBNP Building Network Program 2022	To support international travel for Engineering early-career academics that will lead to new prestigious research collaborations.	Monash University		6,200
Qingdong Ou	Monash Science Strategic Uplift Seed Funding Scheme	Seed funding to strategically enhance research collaboration	Monash University		20,000
Qile Li	Norris Family Commendation for Outstanding Author Contribution by a Graduate Research Student to a published 'quality' scholarly research output	For publication: 'Large magnetic gap in a designer ferromagnet-topological insulator-ferromagnet heterostructure in Advanced Materials.'	Monash University		
Baoyue Zhang	RMIT Vice Chancellor's Postdoctoral Fellowship		RMIT University		
Priyank Kumar	UNSW GROW Grant	A machine learning framework to optimize perovskite composition	University of New South Wales Sydney		54,000
Priyank Kumar	UNSW RNA Institute Seed Grant		University of New South Wales Sydney		70,000
Pankaj Sharma	UNSW Science Faculty Research Grant 2022		University of New South Wales Sydney		8,000
Tich-Lam Nguyen	Women in Leadership Development - WILD for STEM scholarship	A six-month programme to undertake the Company Directors course with the Australian Institute for Company Directors and leadership training with Women In Leadership Development (WILD) for STEM. WILD is a national initiative to boost STEM based women's leadership and governance capabilities.	Other external funding		10,000

Centre finance

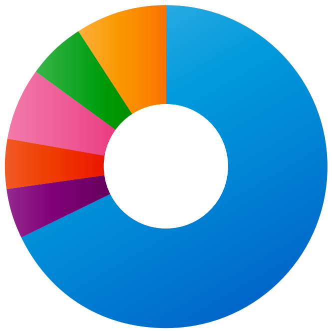
2022-2023 FINANCIAL STATEMENT

REPORTING PERIOD	2022	2023 CURRENT PERIOD
Carry Forward From 2021	**5,775,848**	
INCOME	**ACTUAL $**	**FORECAST $**
ARC (includes indexation)	5,269,072	4,800,000
Monash University	496,000	496,000
University of New South Wales	404,667	404,667
RMIT University	155,000	154,667
Swinburne University of Technology	116,000	116,000
Australian National University	87,000	58,000
University of Queensland	58,000	58,000
University of Wollongong	58,000	58,000
Industry contribution (SUT)	5,962	-
TOTAL INCOME	**6,649,701**	**6,145,334**
EXPENDITURE	**2022 ACTUAL $**	**2023 FORECAST $**
Personnel	4,937,881	5,300,000
- Salaries	4,592,384	-
- Scholarships	345,498	-
Equipment	319,555	117,474
Maintenance & consumables	445,519	393,798
Travel and visitor support	383,498	334,233
Other	623,442	628,000
- Workshops and conferences	165,105	-
- Management and administration	110,227	-
- Education, outreach and communications	89,466	-
- Centre strategic investment	258,644	-
TOTAL EXPENDITURE	**6,709,895**	**6,773,505**
CARRIED FORWARD TO 2023	**5,715,654**	

2022 ACTUAL INCOME



2022 ACTUAL EXPENDITURE



COLLABORATING ORGANISATION	2022 ACTUAL $	2023 COMMITMENT $
Monash University	1,190,517	773,931
University of New South Wales Sydney	919,349	820,049
RMIT University	480,974	379,032
Swinburne University of Technology	398,925	347,443
Australian National University	169,721	75,837
University of Queensland	67,369	187,924
University of Wollongong	162,641	152,917
Australian Nuclear Science and Technology Organisation	567,306	374,000
Australian Synchrotron	632,612	240,465
Beijing Computational Science and Research Center	48,000	63,000
California Institute of Technology, USA	26,800	26,800
China High Magnetic Field Laboratory	16,000	20,000
Joint Quantum Insitute, USA	106,970	30,000
MacDiarmid Institute - Victoria University of Wellington, New Zealand	18,000	20,000
Max Planck Institute of Quantum Optics, Germany	62,110	34,425
National University of Singapore, Singapore	62,984	99,000
Tsinghua University, China	66,854	118,500
Universitat Wurzburg, Germany	19,512	19,512
University of Camerino	28,258	14,130
University of Colorado Boulder, USA	17,000	17,000
University of Maryland, USA	42,700	62,700
University of Texas, USA	18,000	31,000
Wroclaw University of Science and Technology	26,800	26,800
TOTAL IN-KIND CONRIBUTIONS	**5,149,402**	**3,934,465**

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