FLEET 2020 ANNUAL REPORT

FLEET
ARC CENTRE OF EXCELLENCE IN
FUTURE LOW-ENERGY
ELECTRONICS TECHNOLOGIES

Front cover clockwise from top:

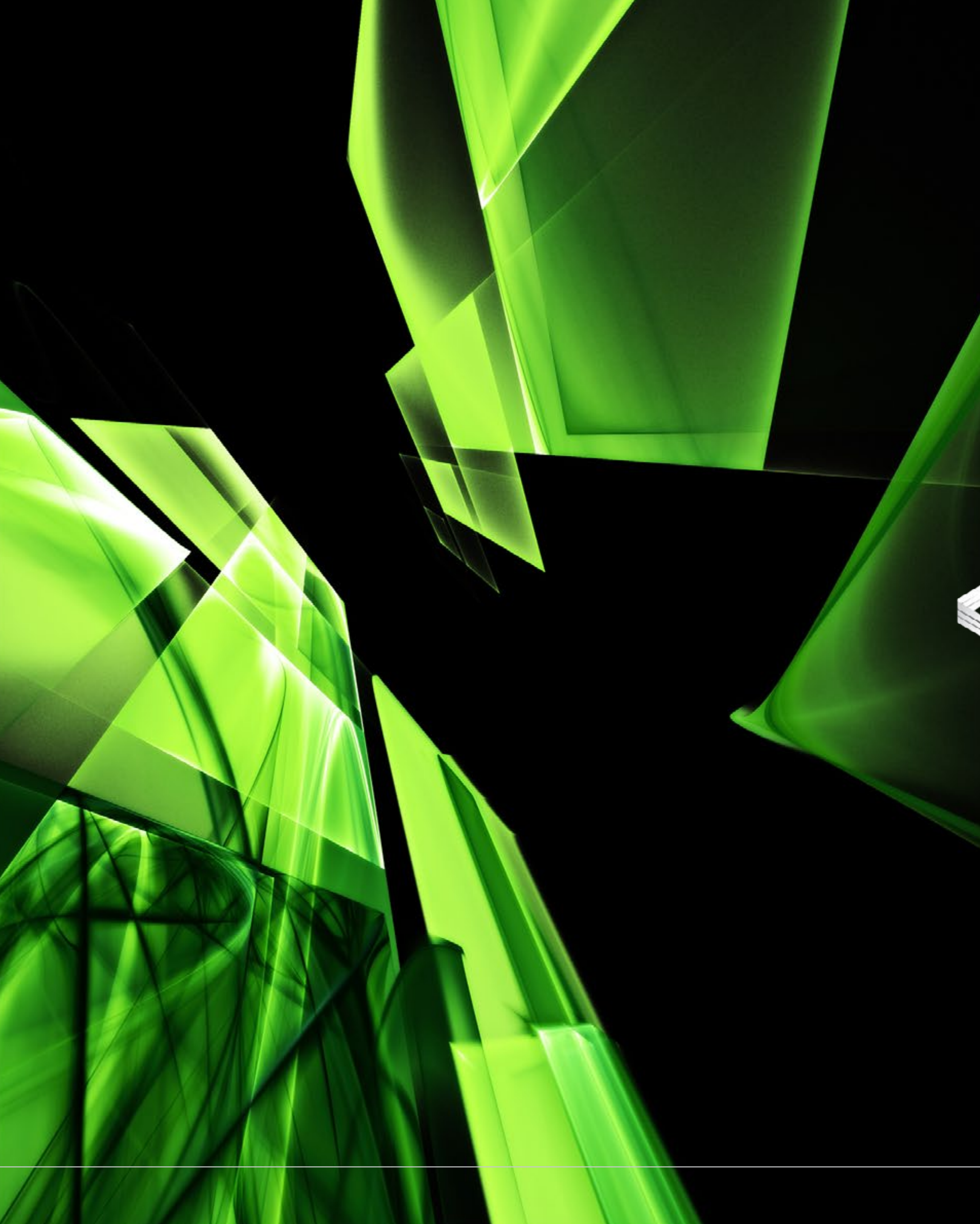
Levitating superconductor
Image courtesy of UNSW

FLEET Scientific Associate Investigator
Dr Chi Xuan Trang (Monash)
Image courtesy of Steve Morton

FLEET PhD student Yonatan Ashlea Alava (UNSW)
Image courtesy of Grant Turner

Back cover clockwise from top:

Scanning tunnelling microscope, Monash
Image courtesy of Steve Morton



FLEET

ARC CENTRE OF EXCELLENCE IN FUTURE LOW-ENERGY ELECTRONICS TECHNOLOGIES

The ARC Centre of **Excellence in Future Low-Energy Electronics Technologies (FLEET)** addresses a grand challenge: reducing the energy used used in information and communication technology (ICT), which now accounts for 8% of the electricity use on Earth, and is doubling every 10 years. The current, silicon-based technology is 40 years old, and reaching the limits of its efficiency. To allow computing to continue to grow, we need a new generation of ultra low energy electronics.

fleet.org.au

INTRODUCTION

INNOVATE

COLLABORATE

EQUITY

ENGAGE

INSIDE FLEET

EDUCATION

PERFORMANCE

CASE STUDIES

FLEET PATHWAY TO IMPACT **2017–2020**

INPUTS

$19.1M
COMMONWEALTH FUNDING

$5.3M
CASH INVESTMENT FROM COLLABORATING ORGANISATIONS

$15M
INKIND CONTRIBUTION FROM COLLABORATING ORGANISATIONS

7
EXISTING INFRASTRUCTURES: AUSTRALIAN UNIVERSITIES

18
EXISTING INFRASTRUCTURES: PARTNER ORGANISATIONS

75
INVESTIGATORS

ACTIVITIES

143
STUDENTS AND POSTDOCTORAL RESEARCHERS BEING TRAINED

30
WORKSHOPS AND CONFERENCES HOSTED

35
SKILL DEVELOPMENT WORKSHOPS HELD

515
OUTREACH ACTIVITIES INVOLVING FLEET MEMBERS

5080
HOURS SPENT ON OUTREACH

71
PRESS RELEASES

OUTPUTS

278
JOURNAL PUBLICATIONS

5
PATENT APPLICATIONS

19
PHD COMPLETIONS

21
POSTDOCTORAL RESEARCHERS TRAINED

830
RESEARCH PRESENTATIONS GIVEN

1158
MEDIA MENTIONS

28,000
PUBLIC AUDIENCE REACHED

>900
SCHOOL TEACHERS ENGAGED

>1800
SCHOOL STUDENTS REACHED

2
POLICY BRIEFS (WOMEN-ONLY RECRUITMENT, INTERNATIONAL ROADMAP FOR DEVICES AND SYSTEMS)

OUTCOMES

1
LM+ TECHNOLOGY SPINOFF – TRANSPARENT CONDUCTIVE OXIDE DEPOSITION

>4000
CITATIONS

"TOPOLOGICAL TRANSISTORS" INCLUDED IN THE INTERNATIONAL ROADMAP FOR DEVICES AND SYSTEMS – BEYOND CMOS

2
INDUSTRY FUNDED PROJECT GRANTS WITH LOCKHEED MARTIN

IMPACT

- Working towards making computing sustainable by reducing the energy used by electronics
- Discovering new materials, processes, devices
- Developing international partnerships and the next generation of science leaders
- Fostering equity and diversity in STEM
- Promoting public STEM literacy
- Training a high-quality workforce in future electronics technologies

VISION

A year of unique challenges underlines FLEET's key challenge

RESEARCH MOMENTUM

FLEET envisions changing the electronics industry, but also changing the way basic research in electronic materials is done.

A few developments of the past year illustrate the changes driving FLEET, and the changes that FLEET is driving.

A YEAR OF UNIQUE CHALLENGES

The lead story of 2020 was an unexpected one, emerging just as last year's annual report went to press.

The COVID-19 global pandemic was a major stress test for every individual, institution and society, and it exposed many hidden faults and weaknesses.

COVID also fundamentally changed many aspects of research – and of work and life in general – but the changes also offered new opportunities. FLEET (and the rest of the world) is still in the midst of this change.

To date, FLEET has managed the crisis portion of the pandemic well, which is a testament to the strength, flexibility and diversity of our team. The next phase will be to learn from the response, and to evaluate the new, changed landscape of collaborative research, using the opportunities those changes present to do even better.

THE PANDEMIC AND ENERGY

FLEET's mission – to develop new, low-energy computing technology – comes as a response to an extrapolation of current trends: energy use in information and computation technology (ICT) is growing unsustainably even while energy use is shrinking in other sectors.

The COVID-19 pandemic has accelerated these trends.

It has been widely noted that overall greenhouse gas emissions will be lower in 2020 than in 2019 (due to decreased economic activity, driving, air travel etc.), while at the same time the ICT industry has seen an unprecedented rise in demand, particularly for energy-intensive streaming video (an issue we wrote about in 2020 for The Conversation).

Moreover, it now seems unlikely that we will return to 'business as usual'. Rather, it appears the pandemic has produced a permanent shift in work culture – to less physical commuting and travel, and to more telecommuting.

This sharp increase in our dependence on digital connection makes FLEET's mission all the more urgent.

RESPONDING TO A CHANGING ENVIRONMENT

Centres of Excellence are designed to address complex, interdisciplinary, long-term problems. But the mix of planning and flexibility required to meet these challenges also can make Centres more resilient to systemic shocks. The shock presented by COVID-19 required a shift in strategy on many fronts.

At their core, Centres are about collaboration and communication: within the Centre, with our partners and with external stakeholders.

Faced with the unique challenges of 2020, FLEET had to rethink how we accomplished collaboration and communication at every level.

Some collaborative activities required in-person presence (for example, in laboratories) and were simply impossible under COVID restrictions. This delayed some research, but FLEET exploited its networks to work around many problems and minimise disruptions.

This report details the many ways FLEET adapted in response to the pandemic. Our response to the pandemic (see the boxed text Responding to 2020) shows the strength of the community FLEET has built and the advantage of having a diverse group generating diverse ideas for change.

We have already begun to learn from the lessons of 2020 by surveying our membership about the effects of COVID on their work and about our (online) annual workshop.

Some things are already clear. The effects of the pandemic are extremely mixed: some found working from home extremely difficult while others found they could be more productive. Surprisingly, we found that some aspects of communication improved during the pandemic. The ‘tyranny of distance’ that has historically handicapped Australian research was greatly reduced: when everyone is online, everyone is equally close (or far)!

But our surveys also identified perhaps the most difficult aspect to replace: the intangible social cohesion that comes from in-person events and meetings. The challenge is to learn which aspects of collaboration can be replaced with virtual presence and which cannot. And we need to develop new, efficient ‘best practices’ for operating in a more digitally connected, but less physically connected, post-pandemic world.

THE PANDEMIC AND EQUITY

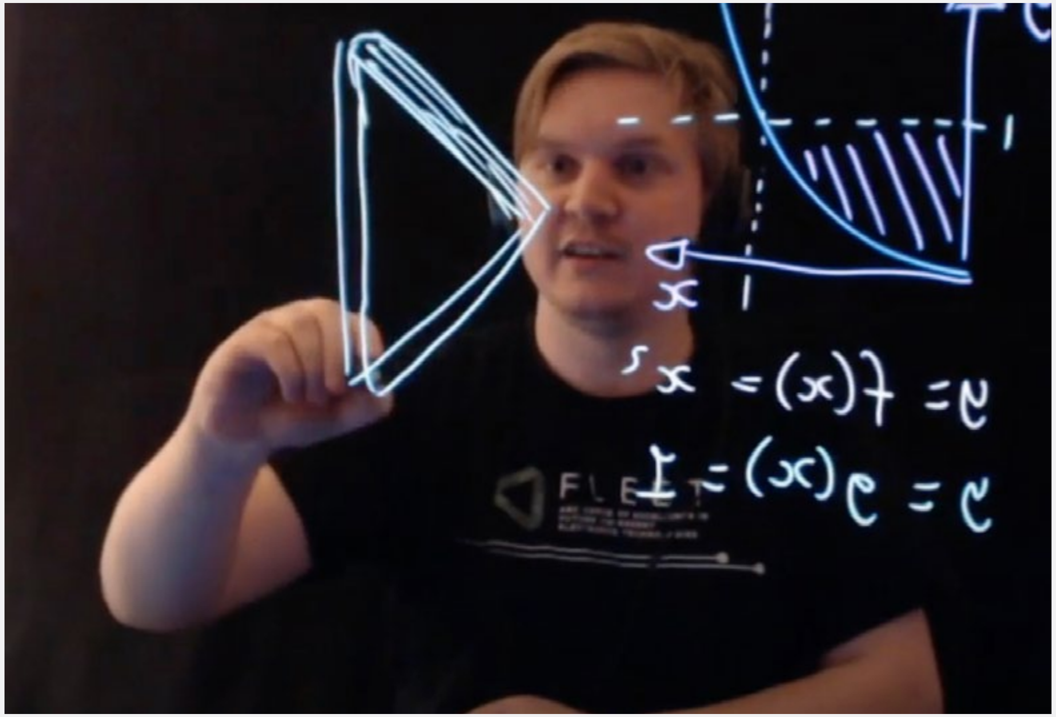
In addition to addressing complex problems, Centres of Excellence also have the capacity to change research culture. For example, FLEET’s mission includes improving gender equity in STEM research. Here again, the global pandemic brought both unique challenges and promising new opportunities.

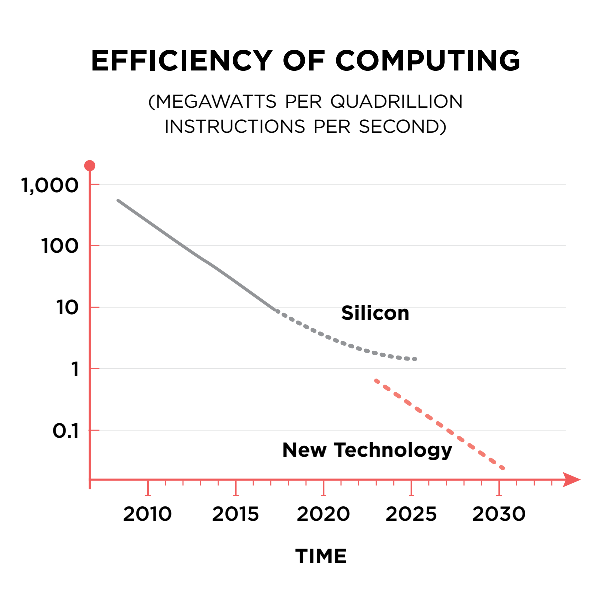
A particular challenge is the way the impacts of the pandemic have fallen more heavily on caregivers and early-career researchers. Experience suggests that these impacts will accordingly fall on young women more heavily, affecting career advancement.

This report describes some of the actions FLEET has taken to mitigate those impacts.

Moving forward, however, we see new opportunities. The post-pandemic world will likely see permanent shifts in work culture towards more flexible work arrangements, more work from home and less travel. These are aspects already identified as helping to create a more equitable environment that does not disadvantage caregivers, who are more likely to be women.

We will work to fully realise these gains and understand what new opportunities will be possible as we overcome the pandemic.





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

FLEET'S GRAND CHALLENGE: A SUSTAINABLE FUTURE FOR COMPUTING

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.

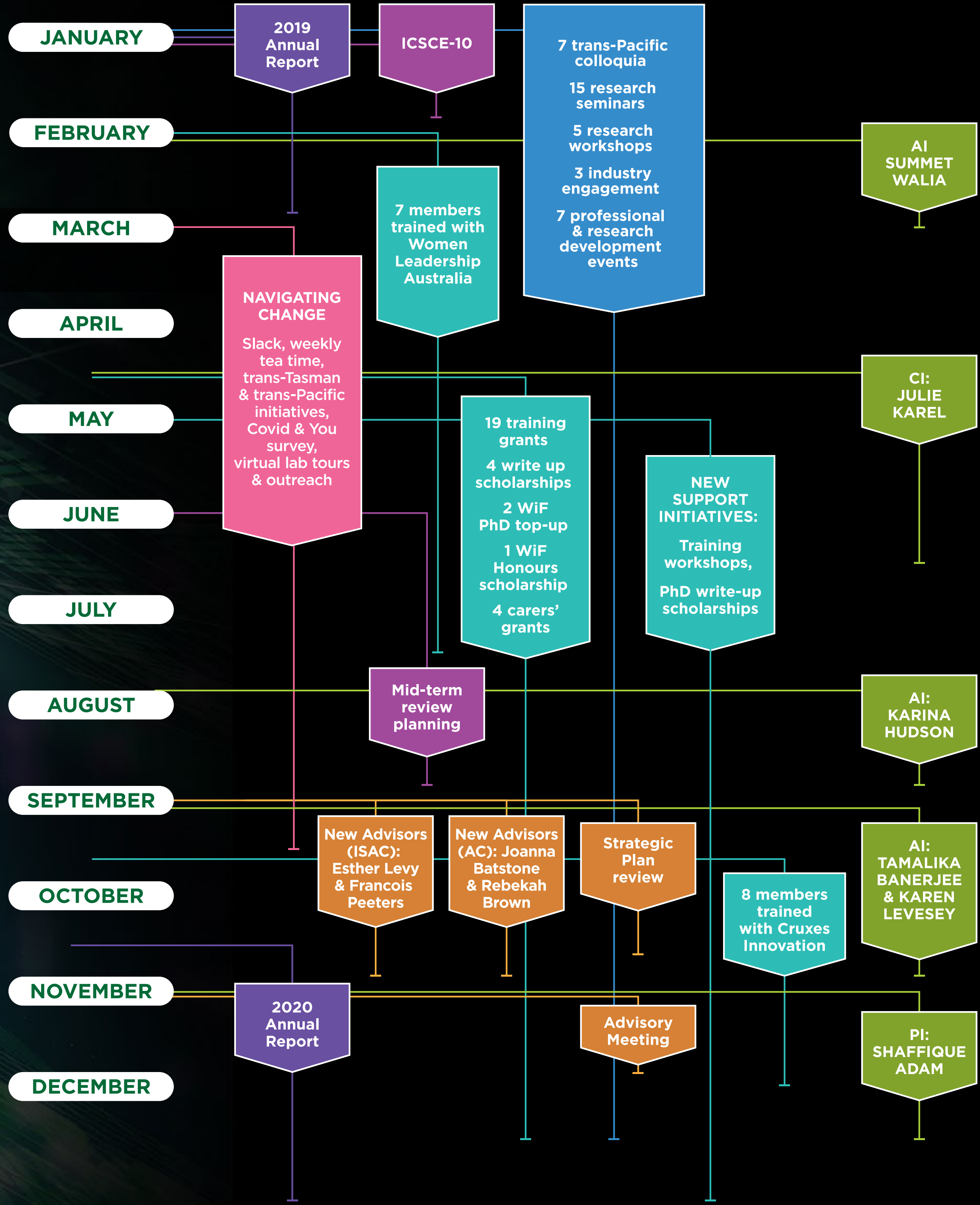
And each time one of those transistors switches, a tiny amount of energy is burnt.

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.

TIMELINE



JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
2019 Annual Report
ICSCE-10
7 trans-Pacific colloquia
15 research seminars
5 research workshops
3 industry engagement
7 professional & research development events
AI SUMMET WALIA
7 members trained with Women Leadership Australia
NAVIGATING CHANGE
Slack, weekly tea time, trans-Tasman & trans-Pacific initiatives, Covid & You survey, virtual lab tours & outreach
CI: JULIE KAREL
19 training grants
4 write up scholarships
2 WiF PhD top-up
1 WiF Honours scholarship
4 carers' grants
NEW SUPPORT INITIATIVES:
Training workshops,
PhD write-up scholarships
Mid-term review planning
AI: KARINA HUDSON
New Advisors (ISAC): Esther Levy & Francois Peeters
New Advisors (AC): Joanna Batstone & Rebekah Brown
Strategic Plan review
8 members trained with Cruxes Innovation
AI: TAMALIKA BANERJEE & KAREN LEVESEY
2020 Annual Report
Advisory Meeting
PI: SHAFFIQUE ADAM

2020 HIGHLIGHTS

Topological transistors included in the IEEE international semiconductor roadmap

Spin-off company LM+ Technology initiated with FLEET investigators Prof Kourosh Kalantar-zadeh and Dr Torben Daeneke

A/Prof Meera Parish awarded an ARC Future Fellowship

Prof Matt Davis, Prof Kris Helmerson and A/Prof Sumeet Walia named finalists in the Australian Museum Eureka Prizes

Five new investigators and four advisors – increasing participation of women at higher levels

Two patents filed: topological switching (Monash and UNSW) and superior thermoelectric materials (UOW)

Pushing the boundary with virtual FLEET workshop

Prof Kourosh Kalantar-zadeh awarded the Royal Society of Chemistry Robert Boyle Prize analytical science

Nine PhD completions in 2020

Fruitful training and communication collaborations with Trans-Tasman and Trans-Pacific partners

MESSAGE FROM THE DIRECTOR

An extraordinary level of scientific output, and FLEET's response to COVID-19 in 2020

2020 is FLEET's third full year of operations. In 2020 FLEET comprised 20 chief investigators at seven Australian node universities, 26 partner investigators at 18 institutions worldwide, 45 postdoctoral fellows and 65 HDR students.

The COVID-19 pandemic disrupted laboratory work in 2020, so research efforts were redirected towards publishing work in progress and exploring new theoretical directions.

Significant progress was also made in organising and publishing major reviews and perspective articles highlighting progress in FLEET research areas. These included reviews of multiferroics for future low-energy data storage, electrical transport in 2D topological materials, and the quantum anomalous Hall effect (QAHE) and spin-gapless semiconductors.

Additional reviews on the topological Dirac semimetal Na_3Bi and ferromagnetic proximity coupling for engineering topological phases are in press.

The result has been an extraordinary level of scientific output in 2020, especially in high-impact journals.

In 2021, FLEET will see a renewed and energetic focus on laboratory work to make up for lost time in 2020.

ADAPTING TO COVID-19

The COVID-19 pandemic required major adjustments to many aspects of FLEET's program. In response to restrictions on travel, FLEET instituted a virtual Trans-Pacific Colloquium series particularly focused on bringing FLEET researches together with partners and stakeholders in North America (see case study), FLEET co-hosted numerous online events with other Centres of Excellence, the MacDiarmid Institute (NZ), Institute of Electrical and Electronics Engineers (IEEE), ANSTO and others (see article).

While FLEET's face-to-face outreach efforts were necessarily limited in 2020, we innovated new ways to keep our members involved in science outreach. Centre members generated home-science videos at home during lockdown, came up with an inexpensive DIY solution to create a virtual lightboard, and delivered skills workshops on graphics, animation and perfecting the science pitch. Many other activities were adapted to online delivery, including virtual lab tours of FLEET facilities *(image below)* at Swinburne University of Technology, UNSW and Monash (see article).

RESEARCH HIGHLIGHTS

DID YOU KNOW...

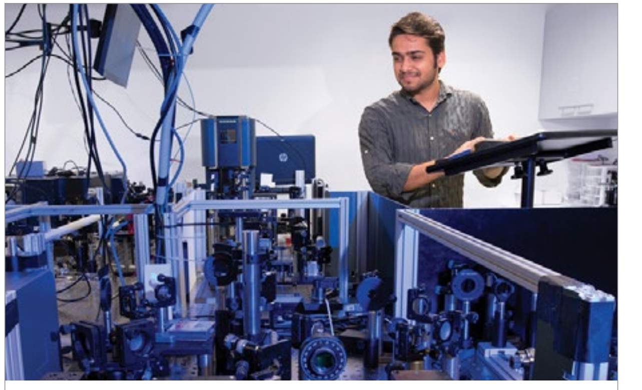
FLEET brought the 10th International Conference on Spontaneous Coherence in Excitonic Systems (ICSCE10) to Australia for the first time in January 2020 (pre-pandemic), testifying to FLEET's international leadership in this field (see article).

RESEARCH THEME 1

FLEET's topological materials researchers (Research theme 1) showed that a topological quantum field-effect transistor (TQFET) can in principle switch at voltages smaller than predicted by the long-standing theoretical limit termed 'Boltzmann's tyranny'.

This places the TQFET as one of less than a handful of device concepts that can achieve low-voltage switching while using electronic charge as the carrier of information. A patent application has been lodged on the basis of the results. Research theme 1 has also made significant advances in understanding magnetic topological insulators, measuring for the first time the magnetism-induced topological bandgap in $MnBi_2Te_4$. Additionally the team had major input into the 2020 edition of the Internationl Roadmap for Devices and Systems, the semiconductor industry's roadmap for future technologies, with the addition of the topological quantum field-effect transistor as a concept for 'beyond CMOS' devices.

Go to Research theme 1

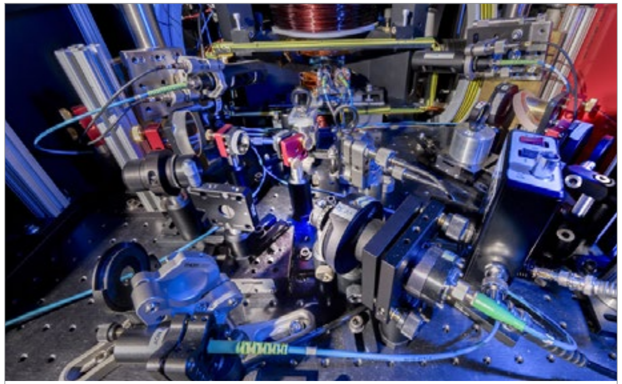


RESEARCH THEME 2

FLEET's exciton superfluids collaboration demonstrated strong coupling of excitons in an atomically-thin semiconductor (WS_2) to light, forming exciton-polaritons at room temperature. This is a further step towards room-temperature condensation of exciton-polaritons in atomically-thin semiconductors.

In a truly multidisciplinary collaboration involving researchers at ANU, Monash University and RMIT University, FLEET researchers solved a long-standing problem in the field of atomically-thin materials – using liquid-metal synthesis (previously developed in FLEET) to produce an atomically-thin, large-area, chemically-inert glass coating that encapsulated and protected atomically-thin semiconductor layers while preserving their excellent optical properties. This process is a key step in fabricating the stacks of atomically-thin semiconductor layers necessary to achieve exciton-polariton condensation.

Go to Research theme 2

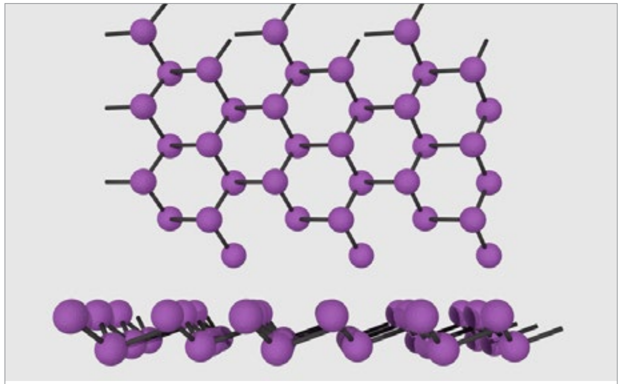


RESEARCH THEME 3

FLEET's light-transformed materials team (Research theme 3) brought online at Monash University a new facility for ultra-fast spectroscopy of 2D materials. This facility will allow researchers to modify materials' properties dynamically using an optical or infrared 'pump' light pulse of femtosecond duration, and to interrogate the resulting real-time femtosecond changes to materials' properties using terahertz probe pulses.

Theme 3 researchers also demonstrated femtosecond-timescale control of the bandstructure of atomically-thin semiconductors WS_2 and MoS_2. Theme 3 gained a better understanding of interactions in dynamical systems, developing the theory for quantum impurities and experimental techniques to probe sound propagation in Fermi gases.

Go to Research theme 3

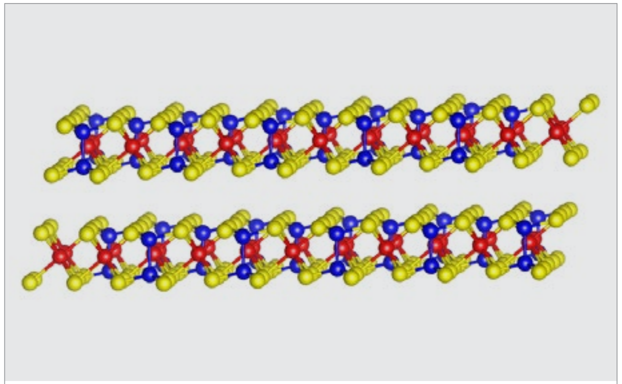


ENABLING TECHNOLOGY A

FLEET's materials researchers (Enabling technology A) synthesised high-quality crystals of 3D topological insulators and magnetic topological insulators showing topological properties up to 50 degrees Kelvin. These crystals are now being used across FLEET to fabricate topological devices.

Theme A researchers discovered high thermopower in a topological insulator/nanoparticle composite. High-thermopower materials are promising for harvesting energy from waste heat, and a patent application was filed for the new material.

Go to Enabling technology A



ENABLING TECHNOLOGY B

FLEET's nano-device fabrication team (Enabling technology B) demonstrated a novel way to control the ferromagnetic coupling in the van der Waals ferromagnet Fe_3GeTe_2 by using an electrochemical 'gate' to inject protons in between the layers of the material.

The liquid-metal technique for deposition of ultra-thin material layers (developed previously in FLEET) was expanded to piezoelectrics and carbon-based materials. Ferroelectric oxide hetero-structures were engineered to exhibit a novel negative differential resistance behaviour, also the subject of a patent application.

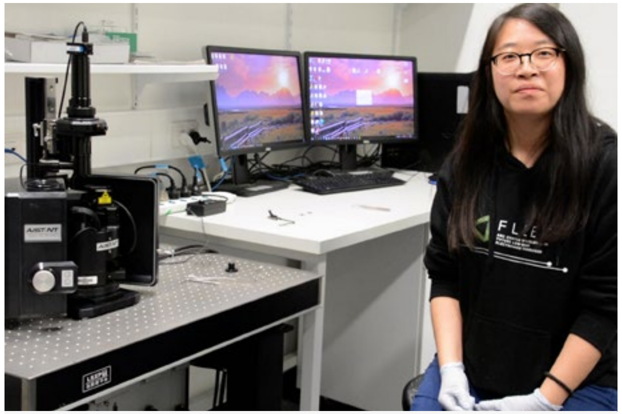
Go to Enabling technology B

ADVANCING EQUITY IN STEM

FLEET addressed its need to increase participation of women at higher levels in 2020, up to 32% of the Centre's advisers and liaisons and 22% of investigators. Overall, with 27% women across the Centre, we are approaching but still short of our overall target of 30% representation of women at all levels.

FLEET identified that while the impacts of the pandemic were varied, they particularly fell on caregivers and those in early in their career.

In response, FLEET ran career training for PhD students who will be job hunting post-pandemic, offered write-up scholarships for Honours and PhD students, reduced KPI requirements for outreach hours, and incorporated a mental-health and wellbeing panel into the Centre's annual workshop.



In 2020 FLEET expanded Women in FLEET funding to cover Honours and PhD students

Additionally, FLEET reviewed its mentorship programs, encouraging members to take advantage of these during the pandemic, and expanded Women in FLEET funding to cover Honours and PhD students (see Women in FLEET).

2021 CENTRE PRIORITIES

- Incorporate lessons learned from COVID, and post-COVID changes in work culture, to design new best practices for Centre collaboration, communication, education, engagement, and equity programs
- Expand equity programs to include other minority groups
- Recruit and retain female early career researchers – to reach a 2021 target of 30%
- Develop strategies to evaluate Centre impact
- Further industry-engagement effort by establishing links with semiconductor foundries and design
- Prepare for upcoming Centre mid-term review

RESPONDING TO 2020

FLEET's responses to the unique challenges of Covid-19 and isolation in 2020 included:

- Extraordinary outreach efforts in the absence of face-to-face events – (see Engage)
- Surveying our people to identify additional support requirements – (see case study)
- Relaxing outreach KPI targets where appropriate for our members' wellbeing
- Moving FLEET's annual workshop entirely online, using a new virtual-meeting platform – (see case study)
- Sharing personal experiences via a mental-health and wellbeing panel
- Increasing Zoom-based seminars and talks: transpacific series (see case study), Australian Institute of Physics – Australian Research Council (ARC) Centres series (see case study), Centre-wide seminars (see Collaborate)
- Trialling new communication tools – (see Engage)

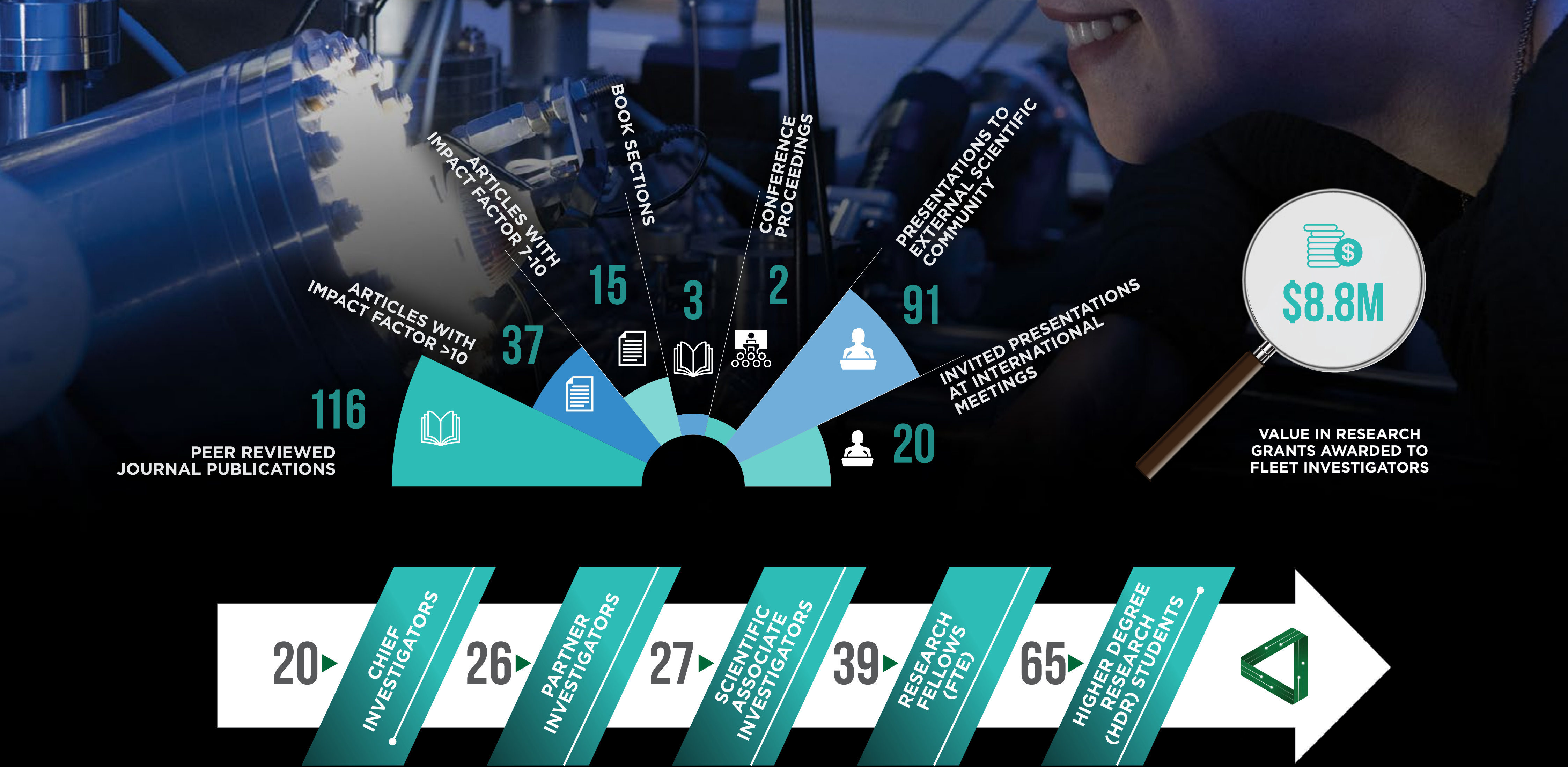
FLEET'S STRATEGIC PRIORITIES

- Enable discoveries at the scientific frontier
- Develop next generation of science leaders
- Establish synergistic partnerships
- Foster equity and diversity in STEM
- Promote public STEM literacy
- Facilitate communication

INNOVATE AT FLEET

FLEET research

Capabilities and Outcomes



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:

These research approaches are enabled by the following technologies:

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.

Read more

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').

Read more

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.

Read more

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.

Read more

ENABLING TECHNOLOGY B:

NANODEVICE 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.

Read more

CHIEF INVESTIGATORS BY THEME

FLEET brings together Australia's leaders in topological electronics, atomically-thin materials, exciton condensates, non-equilibrium phenomena and nanofabrication.

CHIEF INVESTIGATORS

MICHAEL FUHRER
FLEET Director
Monash

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
FLEET Deputy Director
Leader theme 1
UNSW

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 theme 2

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

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

JULIE KAREL
Monash

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

KOUROSH KALANTAR-ZADEH
UNSW / RMIT

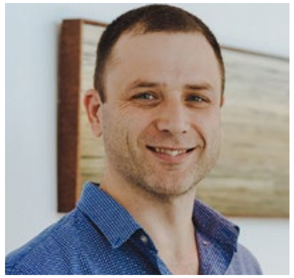
Kourosh develops novel 2D semiconducting materials and fabrication techniques for advanced devices, using electron and ion-beam lithography in Research themes 1 and 3 and Enabling technology B.

KRIS HELMERSON
Monash - Leader theme 3

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 theme B

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

Matt studies transitions between novel non-equilibrium 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 theme 2, she investigates exciton-polariton condensates, while in 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

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

XIAOLIN WANG
UOW - Leader theme A

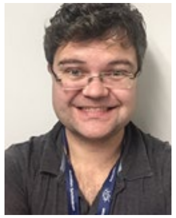
Directing Enabling technology A, Xiaolin investigates charge and spin effects in magnetic topological insulators, and leads synthesis of FLEET's single-crystal bulk and thin-film samples.

FLEET teams

PARTNER INVESTIGATORS

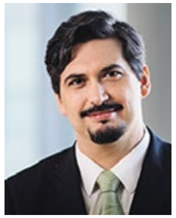
Allan MacDonald
University of Texas

Andrea Perali
University of Camerino



Anton Tadich
Australian Synchrotron

Antonio Castro Neto
National University of Singapore



Barbaros Oezyilmaz
National University of Singapore

David Neilson
University of Camerino

Ferenc Krausz
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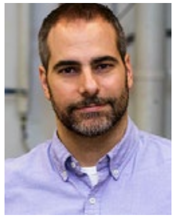

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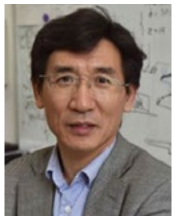

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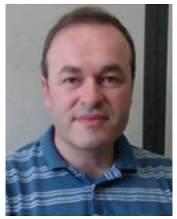

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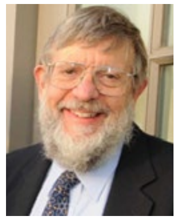

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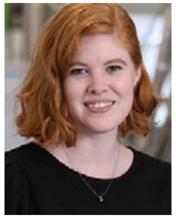

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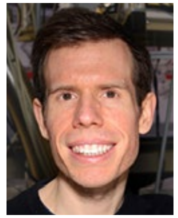

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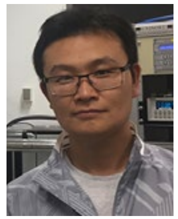

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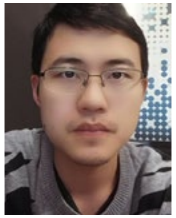

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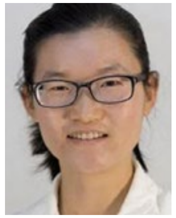

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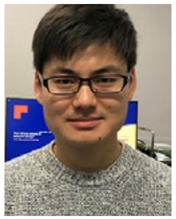

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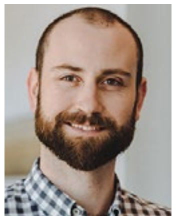

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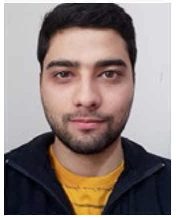

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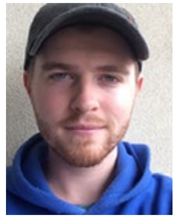

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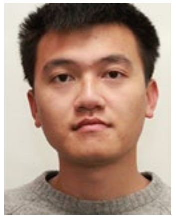

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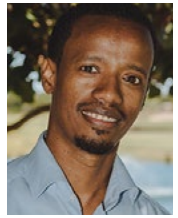

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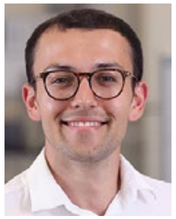

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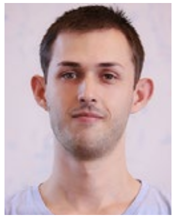

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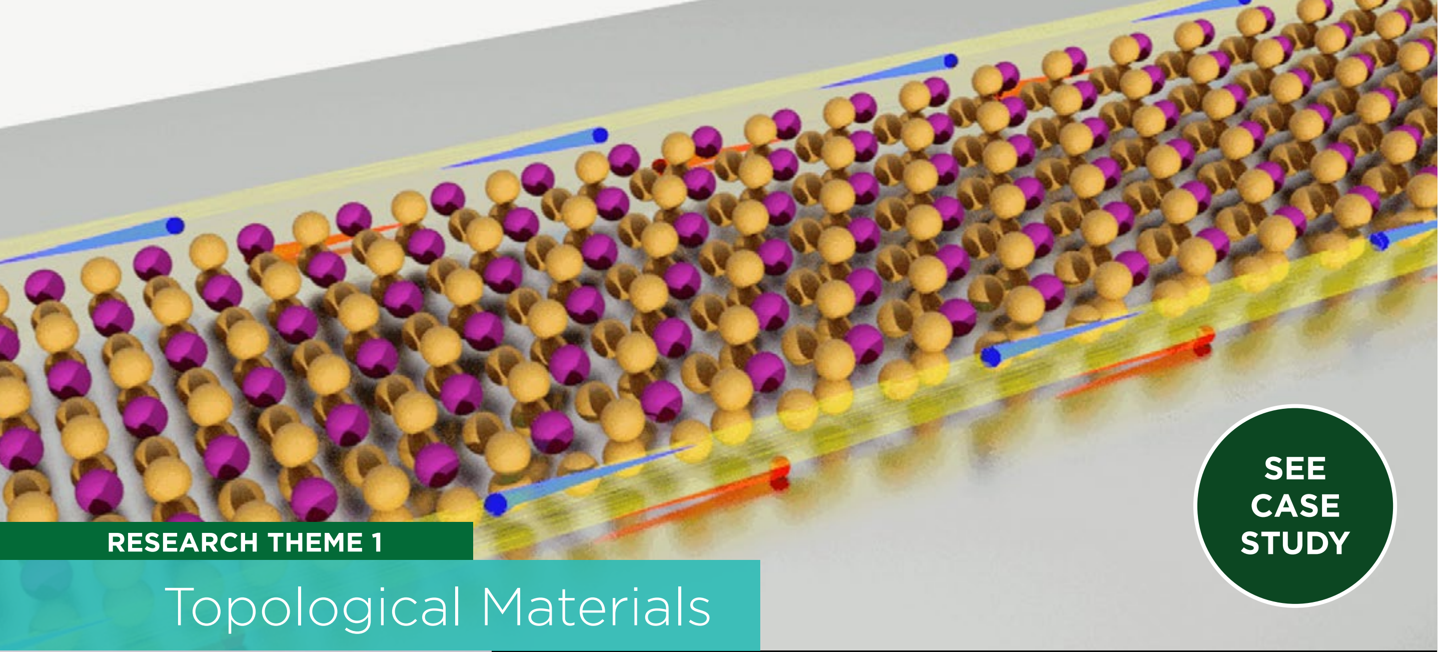


RESEARCH THEME 1

Topological Materials

SEE CASE STUDY

PROF ALEX HAMILTON

Leader, Research theme 1,
UNSW

> 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

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):

270+ papers
4200+ citations
h-index 32 (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.

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.

DID YOU KNOW...

Topological materials represent a paradigm shift in material science that were first proposed in 1987 and only demonstrated in the lab in the last decade. The importance of topological materials was recognised by the 2016 Nobel Prize in Physics, awarded to David Thouless, Michael Kosterlitz and Duncan Haldane.

Research Fellow Semonti Bhattacharyya, Monash University

IN 2021 FLEET WILL...

- Develop new models to understand potential electric-field switching of a **quantum phase transition**, allowing low-voltage switching
- Develop **DFT**-validated, effective tight-binding models for topological materials, and electron-transport models for a prototype topological material
- Study and control magnetic proximity effects at the interfaces of **vdW heterostructures** using electrochemical gating
- Create an artificial **band-structure** in a conventional material by nanoscale patterning
- Fabricate and study self-assembled lattices of metal atoms and organic molecules in a **kagome geometry** on insulating substrates
- Understand the nature of the **bandgap** in 2D topological insulator WTe_2, which is likely an interacting topological insulator.

2020 HIGHLIGHTS

- Demonstrated topological edge-state conduction in Na_3Bi over millimetre distances
- Established new fabrication technique for ultra-low-disorder artificial graphene in conventional semiconductor crystals
- Established crossover from 2D **ferromagnetic** insulator to a **QAHE insulator** in multilayer $MnBi_2Te_4$, which has a large (> 100 meV) **bandgap**
- Demonstrated exchange bias in the 2D vdW ferromagnet Fe_3GeTe_2, and showed that interlayer coupling can be tuned with an electrical gate
- Published multiple review papers, including:
  - review of multiferroics for future, low-energy data storage
  - review of electrical transport in 2D topological materials
  - review of QAHE in magnetic-doped topological insulators and ferromagnetic spin-gapless semiconductors

Demonstrated new, non-linear spin filter for application to **spin-based** electronics devices

DEFINITIONS

Quantum phase transition: A change in the phase of a material that occurs due to a change in a parameter other than temperature, such as electric or magnetic field.

DFT: Density Functional Theory

van der Waals (vdW): heterostructure A structure made by stacking layers of different van der Waals materials

band-structure: The allowed energies for electrons in a material occur in ‘bands’ separated by ‘bandgaps’ which are energy gaps that define whether a material is a conductor, insulator or semiconductor; a large bandgap is required for a material to still be topological at room temperature

Kagome: a periodic arrangement of hexagons and triangles, named after the traditional Japanese woven bamboo basket it resembles.

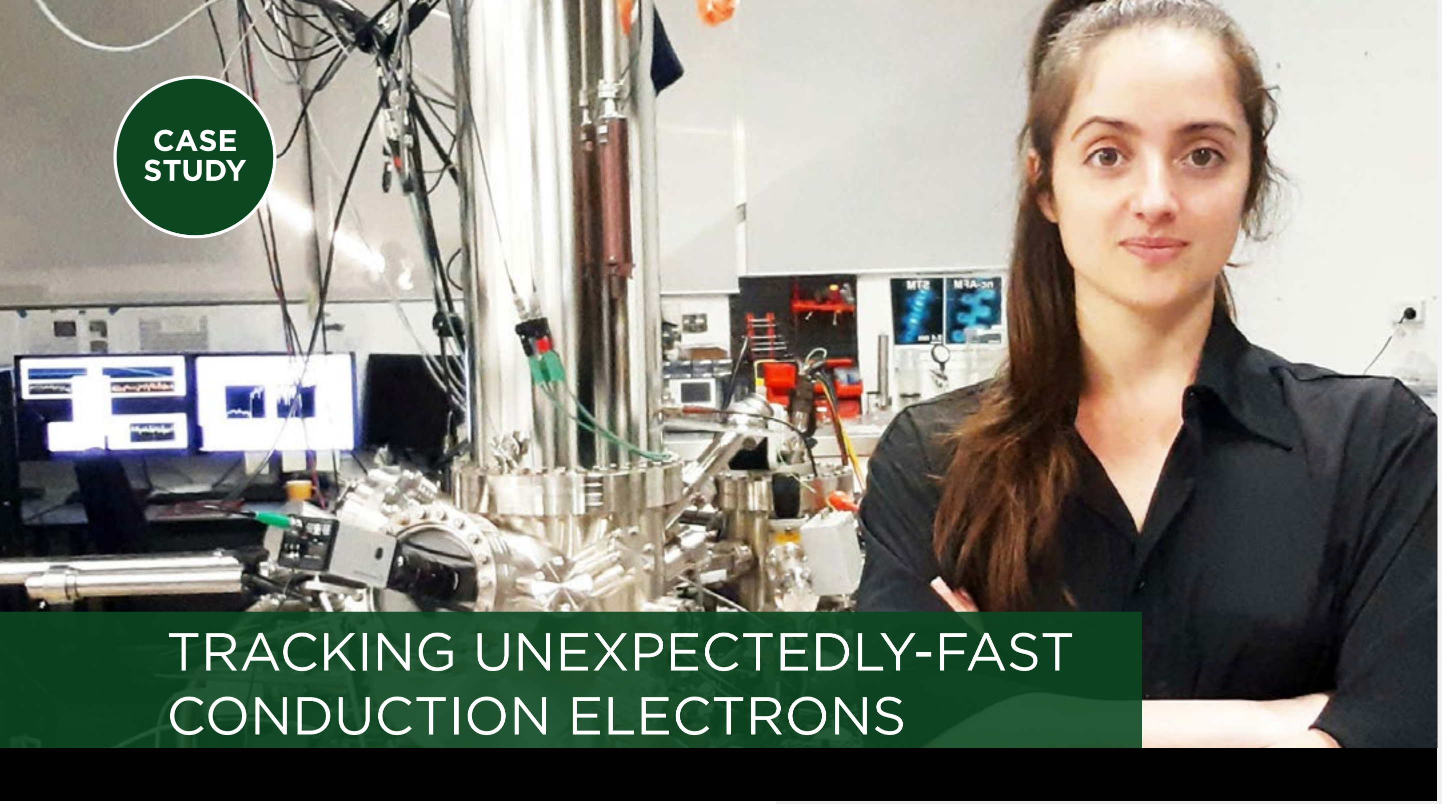
bandgap: The energy gap that defines whether a material is a conductor, insulator or semiconductor; a large bandgap is required for a material to still be topological at room temperature

ferromagnetic materials Material that can be magnetised

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

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

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



TRACKING UNEXPECTEDLY-FAST CONDUCTION ELECTRONS

FLEET study used scanning tunneling microscope (STM) 'trick' to map electronic structure in the topological material Na_3Bi, seeking an answer to its extremely high electron mobility

A 2020 study unlocking the ultra-high electron mobility of topological Dirac semimetals was an exciting step towards use of these materials in future low-energy electronics.

Before this study, little was known about conduction-band dispersion in Na_3Bi, although there had been tantalising hints that the actual velocity of electrons was much larger than theoretical predictions.

High electron mobility is key to this material's potential for ultra-low-energy devices.

"To solve this mystery, we grew thin films of Na_3Bi and investigated their band structure via quasi-particle interference," says lead author FLEET Research Fellow Dr Iolanda di Bernardo (Monash University).

One of the few ways conduction bands can be mapped in such materials is using an STM 'trick' borrowed from spectroscopy.

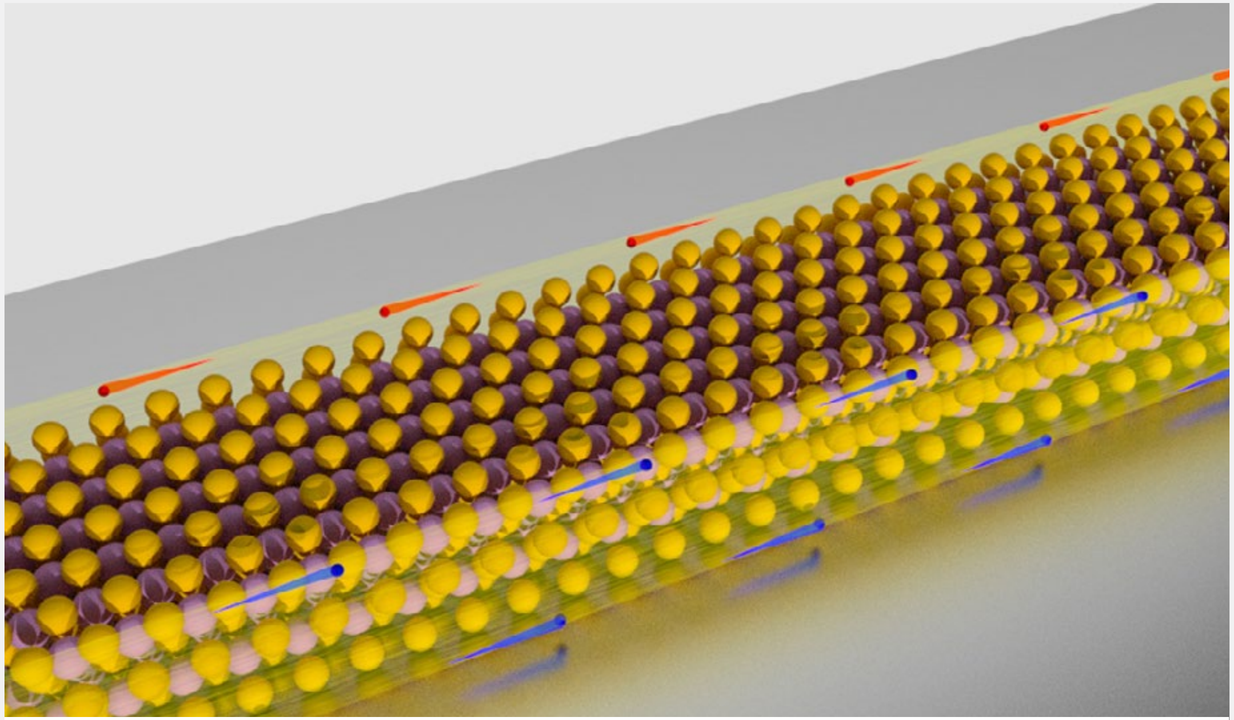
"We 'map' quantum tunneling current between the STM tip and the sample at different voltages," explains Iolanda.

Mathematical analysis of the resulting electron-scattering signal reveals circular energy contours, and reconstruction of (linear) band dispersion in the material indicates electron velocities.

These measured electron velocities in the low-lying conduction and valence bands were significantly higher than theoretical predictions, but the team found one way to significantly improve agreement between measurement and theory.

"We used increasingly complicated models to describe our system, and discovered that as we more-closely modelled exchange and correlation potential, we got closer to the experimental values," explains Iolanda.

> **The exciting thing about condensed-matter physics is when all the pieces of the puzzle come together and you learn something from it.**
>
> Lead author FLEET Research Fellow
> Dr Iolanda Di Bernardo
> Monash



A topological insulator (such as Na_3Bi) allows one-way electrical conduction along its edges

Thus the team confirmed that exchange and correlation effects are crucial to electron mobility in Na_3Bi.

Topological Dirac semimetals can be considered three-dimensional (3D) counterparts of graphene: their conduction electrons display the same linear band dispersion as graphene, meaning their electrons are virtually massless.

This, naturally, translates into extremely high conductivity, which in topological Dirac semimetals, unlike in graphene, occurs in all three directions in space.

Understanding the ultra-high mobilities of carriers in topological Dirac semimetals is a step towards successfully implementing these materials in devices for low-energy electronics.

This research relates to FLEET milestones 1.1 and 1.2.
See page 13 of Strategic Plan

The study was published in ***Physical Review B*** in July 2020 **(see Publications)**

More at **FLEET.org.au/fast-conduction**

Back to Research Theme 1: Topological Materials

Collaborating FLEET Personnel:

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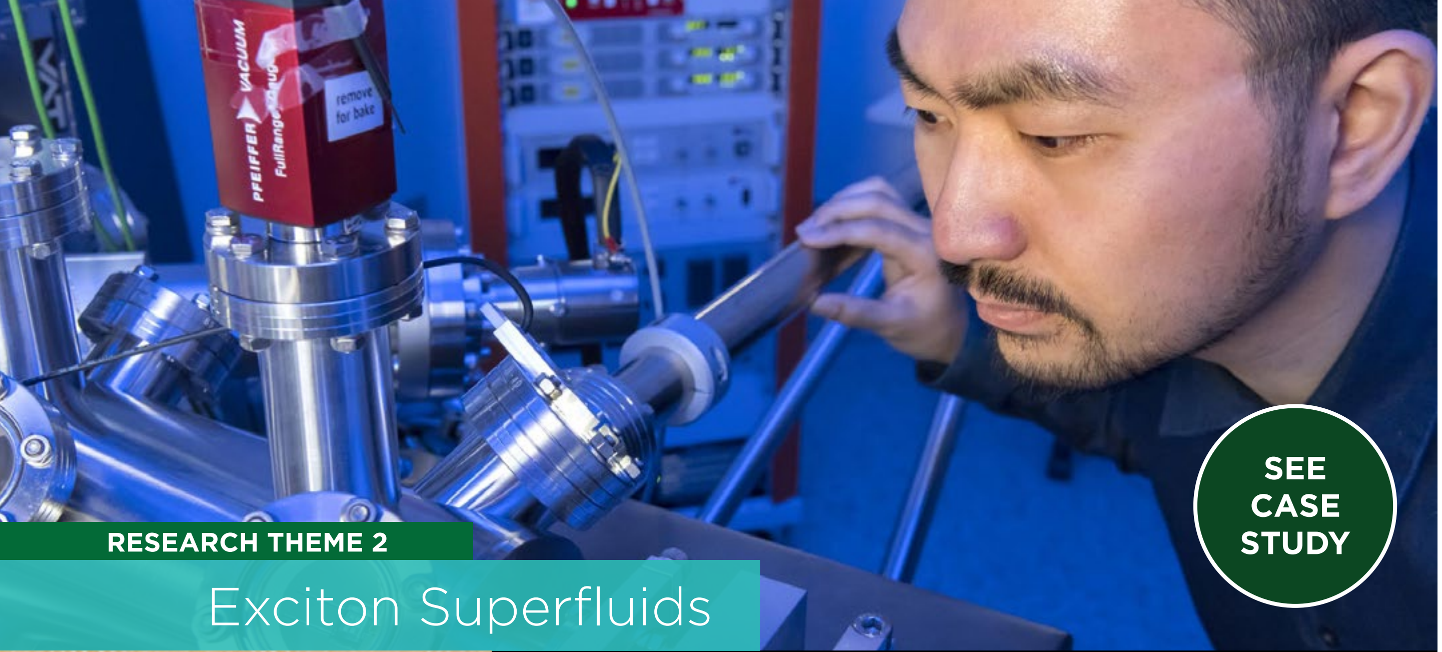
Scientific Associate Investigator
Mark Edmonds

Chief Investigator
Michael Fuhrer

DID YOU KNOW...

The semiconductor industry decadal plan 'seismic shift #5' identifies a mis-match between the growth of computing and available energy capacity.



RESEARCH THEME 2

Exciton Superfluids

SEE CASE STUDY

PROF ELENA OSTROVSKAYA

Leader, Research theme 2,
ANU

> **Research theme 2 highlights FLEET's collaborative nature, involving cross-disciplinary input between nodes and with several Partner Investigators.**

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

Research outputs (Elena Ostrovskaya):

130+ papers
4200+ citations
h-index 35 (Scopus)

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

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

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

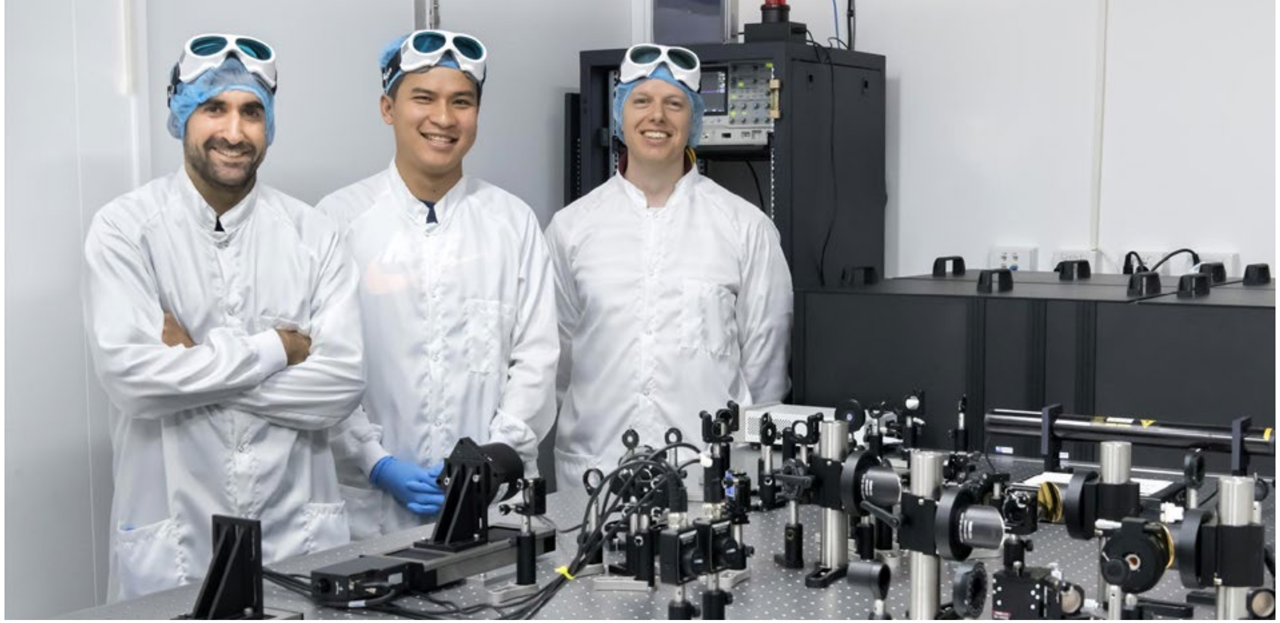
Researchers are seeking to create superfluid flows using three approaches:

- **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.

DID YOU KNOW...

A superfluid is a quantum state in which particles flow without encountering any resistance to their motion. Both excitons and exciton-polaritons can flow in a superfluid.



From left: Chief Investigator Agustin Schiffrin, PhD student Phat Nguyen and Research Fellow Gary Beane, Monash University

DEFINITIONS

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

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

dark excitons: excitons which do not readily recombine to emit light and are therefore long-lived

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

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

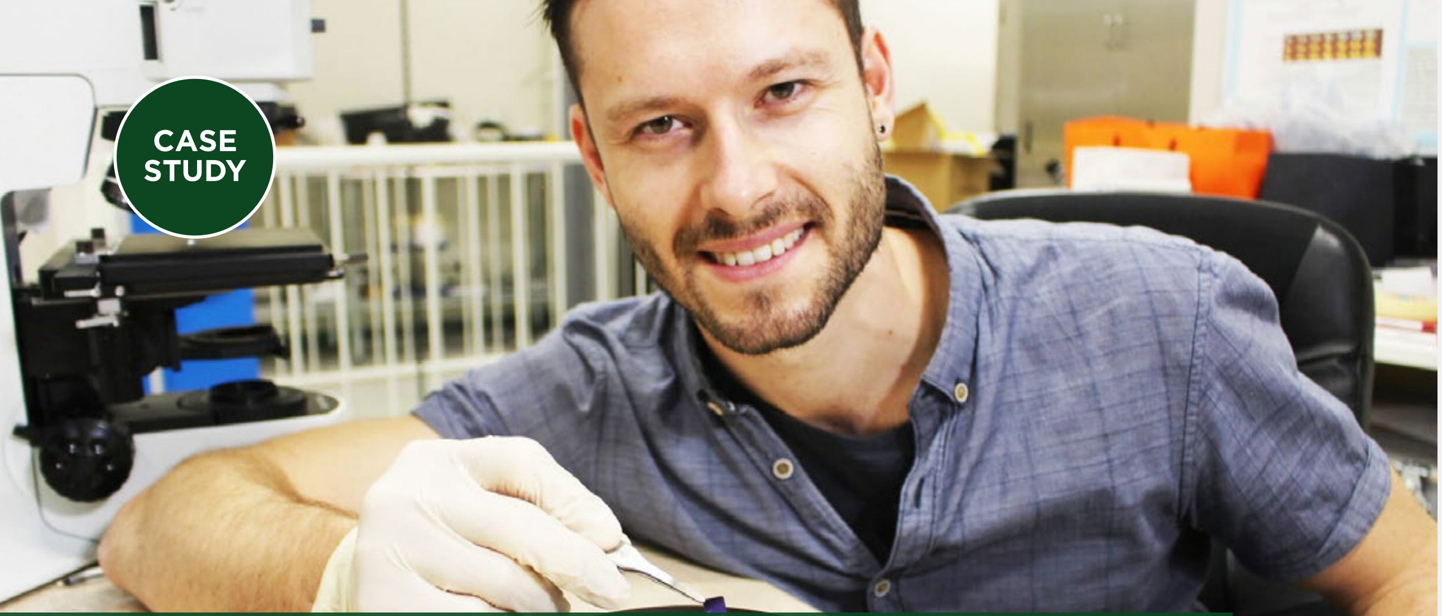
monolithic optical microcavity A micrometre-scale multi-layer structure, in which an active layer hosting excitons is embedded in an optically transparent medium and sandwiched between ultra-reflective mirrors. This structure is used to confine light and make it interact with excitons so that it forms exciton-polaritons.

IN 2021 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 behaviour of dissipative **superfluids** in channels.

2020 HIGHLIGHTS

- Observed room-temperature exciton-polaritons in **monolithic optical microcavities** with embedded tungsten disulfide (WS_2)
- Developed a novel method of protecting WS_2 against further material deposition (see case study) while preserving and enhancing optical properties, enabling future embedding of stacked monolayers in microcavities for exciton-polariton condensation
- Observed quantum depletion of an exciton-polariton condensate, identifying features stemming from system's non-equilibrium nature. Used this system to calibrate exciton-polariton interactions.
- Theoretically showed that stacked atomically-thin (2D) layers of semiconducting **TMD** materials could support exciton superfluidity at elevated ('kitchen fridge') temperatures
- Investigated (theory) interactions between exciton-polaritons in 2D semiconductor layers embedded in a planar microcavity, demonstrating that strong coupling to light enhances the interactions.



ENCASING FRAGILE 2D SEMI-CONDUCTORS IN ULTRA-THIN GLASS

A route towards compact ultra-low-energy electronics

Two-dimensional (2D) semiconductors have emerged during the past decade as extremely promising for future electronic and opto-electronic devices.

However, to unlock the significant potential of these fragile materials, we must first find a way to protect them in functional devices while maintaining their key electronic and optical properties.

A FLEET-led Australian–German collaboration addresses this issue of fragility by providing a high-performance, ultra-thin, protective glass coating.

Incorporating 2D semiconductors in multilayer, solid-state structures on a large scale would allow their integration into functional devices, with exciting potential use in compact, ultra-low-energy electronics.

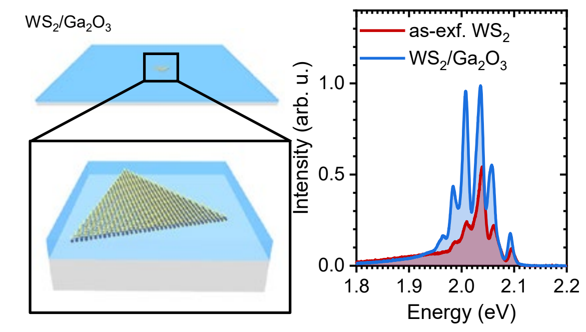
Being only a few layers of atoms in thickness, ‘two-dimensional’ materials are inherently fragile.

“To date, the integration of 2D semiconductors into functional devices has been limited by this fragility, or by the scalability of the protective materials being used,” says lead author Matthias Wurdack (ANU).

“Thus, we need new methods of protection that are cost-efficient and scalable, while maintaining the material’s necessary electronic and optical properties.”

The new study introduces ultra-thin gallium oxide (Ga_2O_3) glass as a new, scalable capping material for monolayer tungsten disulfide (WS_2), a key 2D semiconductor.

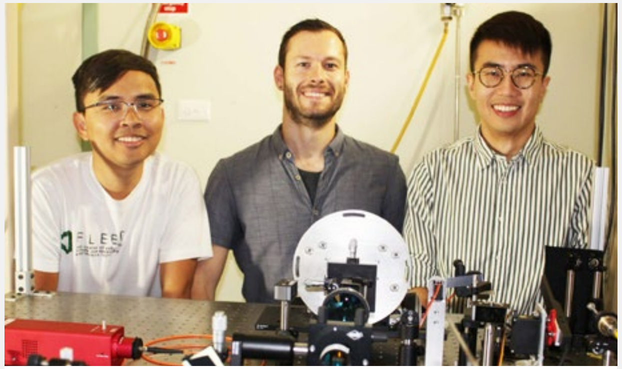
> **We’ve generated a nice alternative to existing technology that can be scaled for industry applications and it would be exciting to see fundamental research like this find its way into industry!**
>
> Lead author, FLEET PhD student Matthias Wurdack, ANU



Fragile, atomically-thin WS_2 is protected by an ultrathin Ga_2O_3 layer, which promotes the electronic signature.

With contributions by FLEET researchers at ANU, Monash University and RMIT, the new paper describes a novel mechanism for extraordinary protection against deposition of dielectric materials.

The target material in the new study, tungsten disulfide, belongs to the group of transition metal dichalcogenide crystals (TMDCs) and is a very promising candidate for various opto-electronic applications functional at room temperature.



ANU researchers: Research Fellow Dr Eli Estrecho, PhD students Matthias Wurdack (lead author) and Tinghe Yun

In these materials the thickness of one or a few layers of atoms, the movement of charge-carrying particles (such as electrons) is confined to only two dimensions, and some fascinating quantum effects predominate.

For example, some particles moving in two dimensions lose their ability to 'scatter', so that electrical resistance vanishes.

Incorporating 2D materials in functional devices is key to the FLEET mission.

To achieve the goals of Research theme 2, FLEET researchers need to incorporate 2D semiconductors (such as WS_2) into a complex multilayer structure – an optical microcavity – that enables the formation of exciton-polaritons.

Exciton-polaritons in WS_2, in particular, can survive at room temperature, and they have the potential to form a quantum superfluid that displays dissipationless transport.

Robust protection of 2D semiconductors is a key enabling technology for integrating these materials into optical microcavities.

Collaborating FLEET Personnel:

Chief Investigator
Professor Elena Ostrovskaya

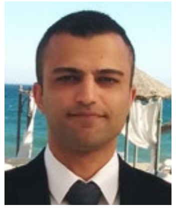
PhD student
Matthias Wurdack

PhD student
Tinghe Yun

Research Fellow
Eliezer Estrecho

Research Fellow
Semonti Bhattacharyya

Research Fellow
Maciej Pieczarka



Research Fellow
Ali Zavabeti
(Alum)

Research Fellow
Shao-Yu Chen

Chief Investigator
Qiaoliang Bao
(Alum)

Scientific Associate Investigator
Yuerui Lu

Chief Investigator
Michael Fuhrer

Scientific Associate Investigator
Torben Daeneke

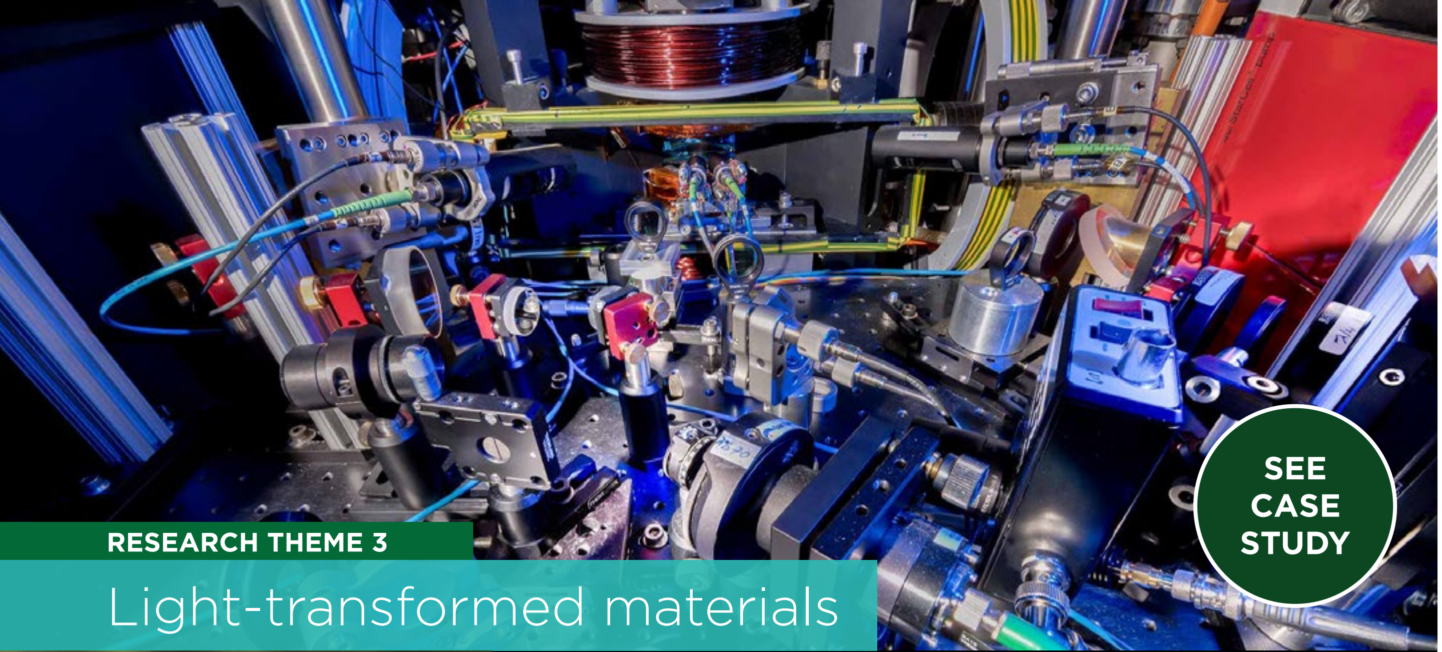
This research relates to FLEET milestones 2.1.1, 2.2.1, and 2.2.4. **See page 16 of Strategic Plan**

More at **FLEET.org.au/protected**

Back to Research Theme 2: Exciton Superfluids

DID YOU KNOW...

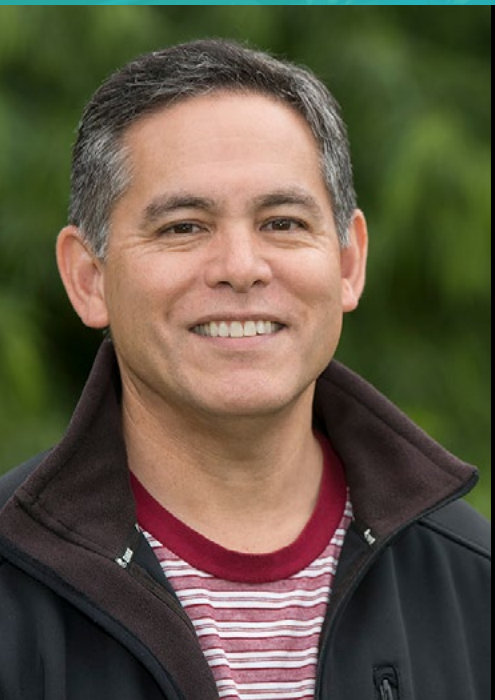
Two-dimensional materials have extraordinary properties such as extremely low resistance or highly efficient interactions with light. However they are inherently fragile.



RESEARCH THEME 3

Light-transformed materials

SEE CASE STUDY



PROF KRIS HELMERSON

Leader, Research theme 3,
Monash

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

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):

110+ papers
4800+ citations
h-index 31 (Scopus)

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

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

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

Very short, intense pulses of light are used to force materials to become topological insulators (see Research theme 1) 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.

DID YOU KNOW...

FLEET researchers cool atomic gases to only a few billionths of a degree above Absolute Zero – a billion times colder than interstellar space.

IN 2021 FLEET WILL...

- Identify topological phase transitions in **Floquet systems** using **terahertz** spectroscopy
- Demonstrate **Floquet control** of bandstructure in graphene
- Investigate quench dynamics in a 2D **Fermi gas** near a ***p*-wave Feshbach resonance**
- Demonstrate Floquet states with **spin-orbit coupling** in an atomic gas
- Develop theoretical understanding of (Floquet) **kicked-rotor system** with spin-orbit coupling
- Demonstrate electric field enhancement for optical control of **band structure**, e.g. via **plasmonic resonances**.

DEFINITIONS

equilibrium state The state in which a material is in balance, unchanging with time

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

topological state: state of matter defined by the topology of the constituent particles; for example whether a material is a conventional insulator or a topological insulator.

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

superfluid A quantum state in which particles flow without encountering any resistance to their motion

Floquet theory: A method to describe systems out of equilibrium in a periodic time-dependent field, such as light.

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

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

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

***p*-wave Feshbach resonance** A non-spherically symmetric (p-wave) collisional interaction between atoms, in which we can tune the strength of the interaction using an external magnetic field (Feshbach resonance).

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

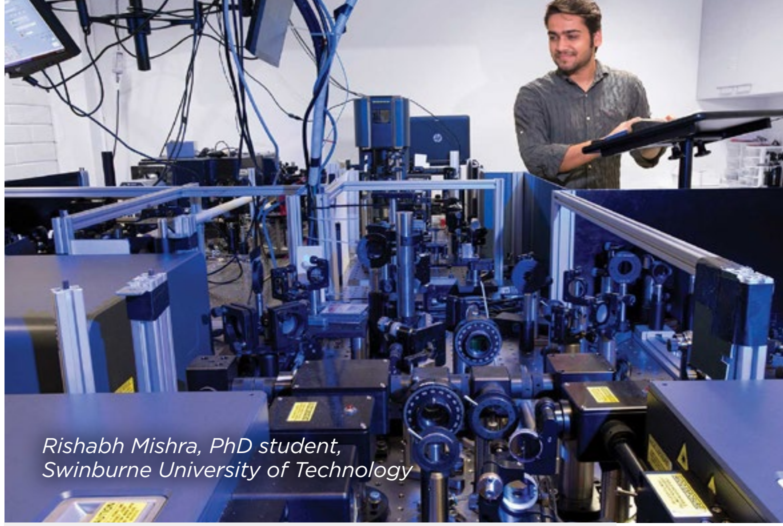
kicked-rotor system A periodically 'kicked' rotating pendulum (kicked-rotor), which can be realised in the laboratory with atoms periodically kicked by laser pulses

bandgap The energy gap that defines whether a material is a conductor, insulator or semiconductor

plasmonic resonance A resonant excitation of the oscillation of conduction electrons in a metal resulting in very large localized electric fields for modifying the band structure of materials.

adiabatic process one in which the system remains in the same quantum mechanical state, even as that state changes

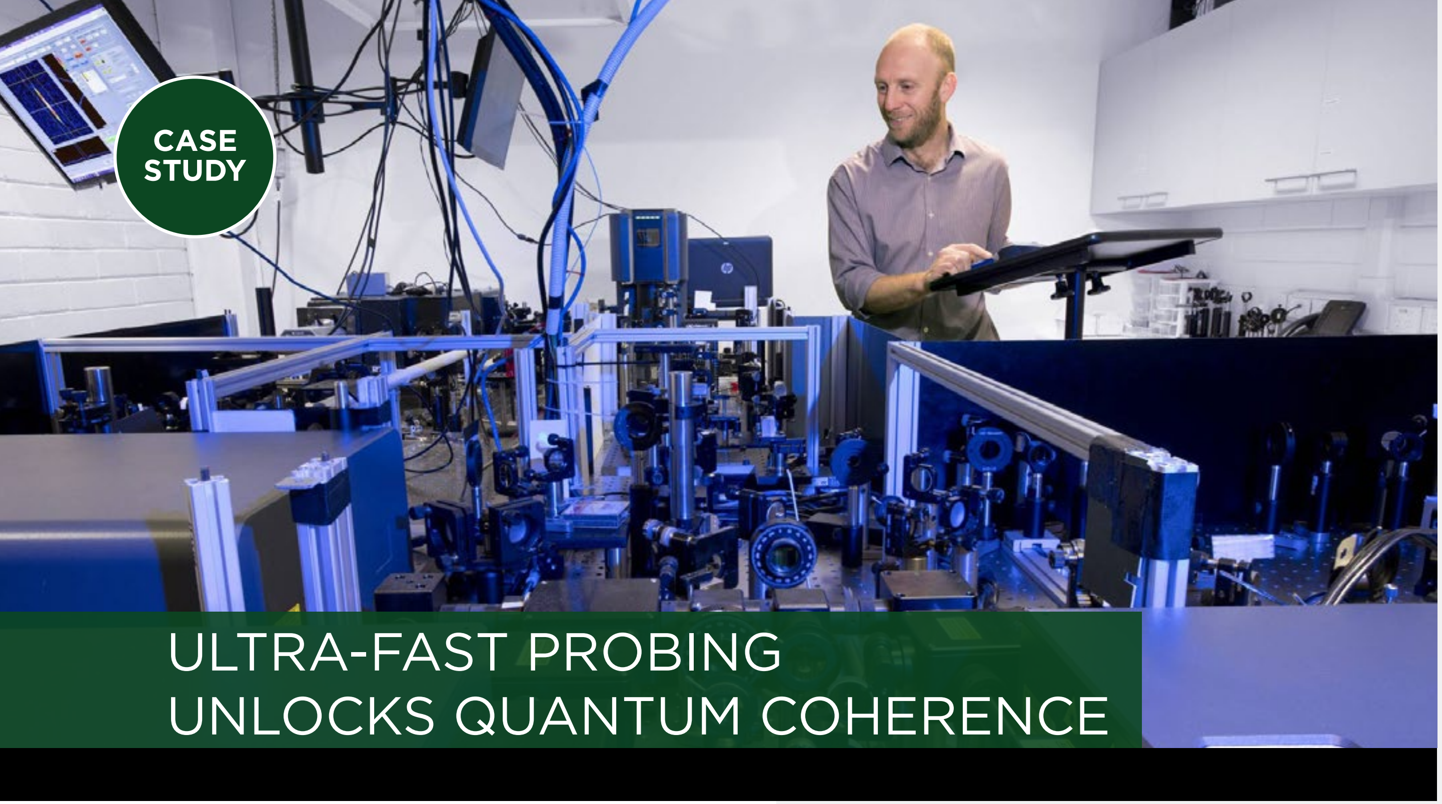
optical pump-terahertz probe: A technique in which a material is first excited by an ultrafast optical light pulse and then analysed by an ultrafast terahertz light pulse, allowing the dynamics of electrons to be probed at sub-picosecond timescales.



Rishabh Mishra, PhD student, Swinburne University of Technology

2020 HIGHLIGHTS

- Demonstrated **Floquet control** of bandstructure in the semiconducting TMD materials WS_2 and MoS_2, with light-controlled band modification shown to be **adiabatic** for pulses below 30 **femtoseconds**, and optical coherence measured between bands
- Developed detailed understanding of mobile quantum impurities in Fermi gases, applying a theory developed for ultra-cold atomic gases to understand absorption in semiconductors
- Established experimental technique to measure sound propagation in ultra-cold Fermi gases, used to understand transport phenomena in strongly-interacting Fermi gases
- Commissioned experimental facility (Monash) to perform **optical pump-probe terahertz probe** time-domain spectroscopy of functional materials
- Revealed coherent dynamics and interactions in a strongly-correlated material using multidimensional coherent spectroscopy.



CASE STUDY

ULTRA-FAST PROBING UNLOCKS QUANTUM COHERENCE

Seeing quantum effects on a macroscopic scale: ultra-fast, multidimensional spectroscopy unlocks macroscopic-scale effects of quantum correlations

A 2020 FLEET study unlocks intriguing magnetic and electronic properties of quantum materials that hold significant promise for future technologies.

Controlling these useful properties requires an improved understanding of the ways in which macroscopic behaviour emerges in complex materials with strong electronic correlations.

Potentially useful electric and magnetic properties of strongly-correlated quantum materials include topological insulators and high-temperature superconductivity.

Such macroscopic properties emerge out of microscopic complexity, rooted in the competing interactions between the degrees of freedom of electronic states.

To date, measurements of the dynamics of excited electronic populations have largely neglected the intricate dynamics of quantum coherence.

FLEET researchers applied multidimensional coherent spectroscopy to the challenge for the first time, using the technique's unique capability to differentiate between competing signal pathways, selectively exciting and probing low-energy excitations.

The team analysed the quantum coherence of excitations produced by hitting the layered, superconducting material LSCO (lanthanum, strontium, copper and oxygen) with a sequence of tailored, ultra-fast beams of near-infrared light lasting less than 100 femtoseconds.

This produces coherent excitations lasting a surprisingly 'long' time (around 500 femtoseconds), originating from a quantum superposition of excited states within the material.

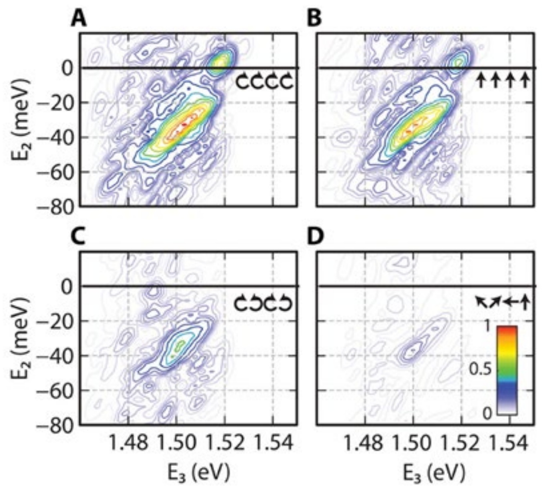
The strong correlation between the energy of this coherence and the optical energy of the emitted signal indicates a coherent interaction between the states at these vastly different energy scales.

This kind of coherent interaction, reported here for the first time, is linked to many intriguing and poorly-understood phenomena displayed by quantum materials.

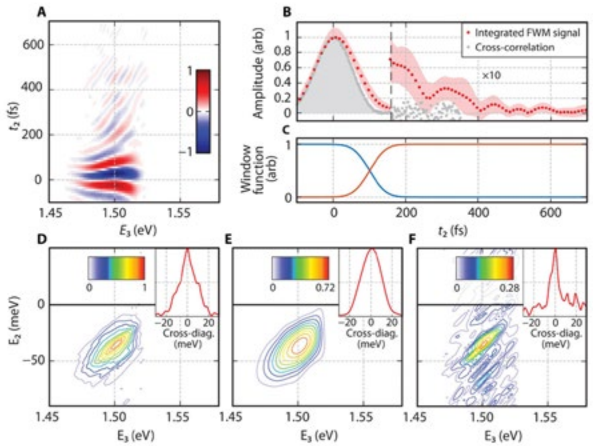
"The strong correlation between the energy of this coherence and the optical energy of the emitted

DID YOU KNOW...

Swinburne University of Technology has the highest concentration of ultrafast laser systems in the southern hemisphere.



Ultrafast spectroscopy reveals minimal effect of polarization



2D spectrum showing energy difference between the states in a quantum superposition

If you want to measure the precise evolution of electrons, which can change their properties or their state in femtoseconds, you need to be able to start and stop the clock really, really quickly. We use femtosecond laser pulses (ie, millionths of a billionth of a second in duration) to achieve this.

FLEET Chief Investigator
A/Prof Jeff Davis

signal indicates a special coherent interaction between the states at low and high energy in these complex systems," says study author A/Prof Jeff Davis (Swinburne University of Technology).

It is one of the first applications of multidimensional spectroscopy to the study of correlated electron systems such as high-temperature superconductors, and it is the first time the technique has been used to interrogate complex quantum materials in this way.

As well as representing a major advancement in ultra-fast spectroscopy of correlated materials, the work has wider significance in optics, photonics, chemistry, nanoscience and condensed-matter science.

This research relates to FLEET milestones 3.1.1.
See page 18 of Strategic Plan

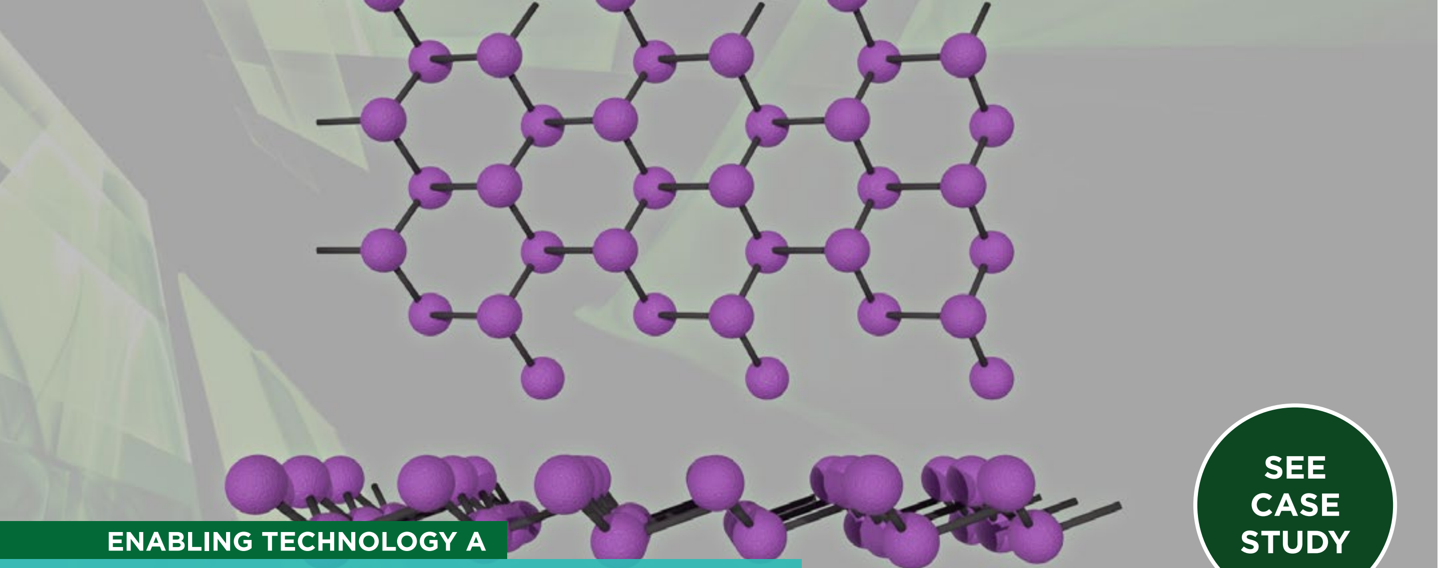
The study was published in ***Science Advances*** in February 2020 **(see Publications)**

More at **FLEET.org.au/ultrafast**

Back to Research Theme 3: Light-transformed materials

Collaborating FLEET Personnel:

Chief Investigator
Jeff Davis



ENABLING TECHNOLOGY A

Atomically-thin materials

SEE CASE STUDY

PROF XIAOLIN WANG

Leader, Enabling technology B,
UOW

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

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

Research outputs (Xiaolin Wang):

530+ papers
13,000+ citations
h-index 57 (Scopus)

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.

DID YOU KNOW...

FLEET scientists use materials that are 'atomically thin' – only one layer of atoms thick. These materials are also referred to as two-dimensional (or 2D).

Research Fellow, Golrokh Akhgar, Monash University

IN 2021 FLEET WILL...

- Continue to supply three-dimensional (3D) **ferromagnetic** topological-insulator crystals, and atomically-thin samples gained using exfoliation from 3D bulk crystals
- Continue to search for new candidates for **QAHE** with high transition temperature
- Apply **MBE, CVD** and liquid-metal approaches to synthesise 2D topological materials
- Use **STM** to observe the bandgap and topological edge modes of a 2D magnetic topological insulator
- Apply new **ARPES** synchrotron techniques for study of 2D topological insulators and surface state of 3D topological insulators
- Novel ferroelectric 2D materials with topological domains.

2020 HIGHLIGHTS

- Synthesised and studied large-scale crystals of a wide-**bandgap** 3D topological insulatorusing high-purity chemicals
- Grew a novel (samarium- and iron-doped) ferromagnetic material Bi_2Se_3 and characterised using quantum electronic transport and **ARPES** techniques
- Created thin magnetic layers at the surface of Sb_2Te_3 topological insulators using a low-energy chromium-ion beam
- Conducted ARPES synchrotron study in **vdW** semiconductor ß'-In_2Se_3 revealing a highly two-dimensional band structure with moderate bandgap and small effective electron mass
- Verified **spin-gapless semiconductors** as the ideal platform for high-temperature QAHE
- Demonstrated record-high thermoelectric performance in nano-engineered topological insulators, with patent filed
- Demonstrated liquid-metal synthesis of improved **piezoelectric** material: atomically-thin tin-monosulfide, with monolayer SnS showing promising **ferroelectric** properties.

DEFINITIONS

ferromagnetic materials Material that can be magnetised

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

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

Chemical vapor deposition (CVD) A vacuum deposition method used to produce high-quality, high-performance, solid materials

Scanning tunneling microscope (STM)

Angle-resolved photoemission spectroscopy (ARPES): A technique in which the energy and momentum of electrons ejected from a material after illumination by X-rays are used to measure the bandstructure of the material.

bandgap The energy gap that defines whether a material is a conductor, insulator or semiconductor

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

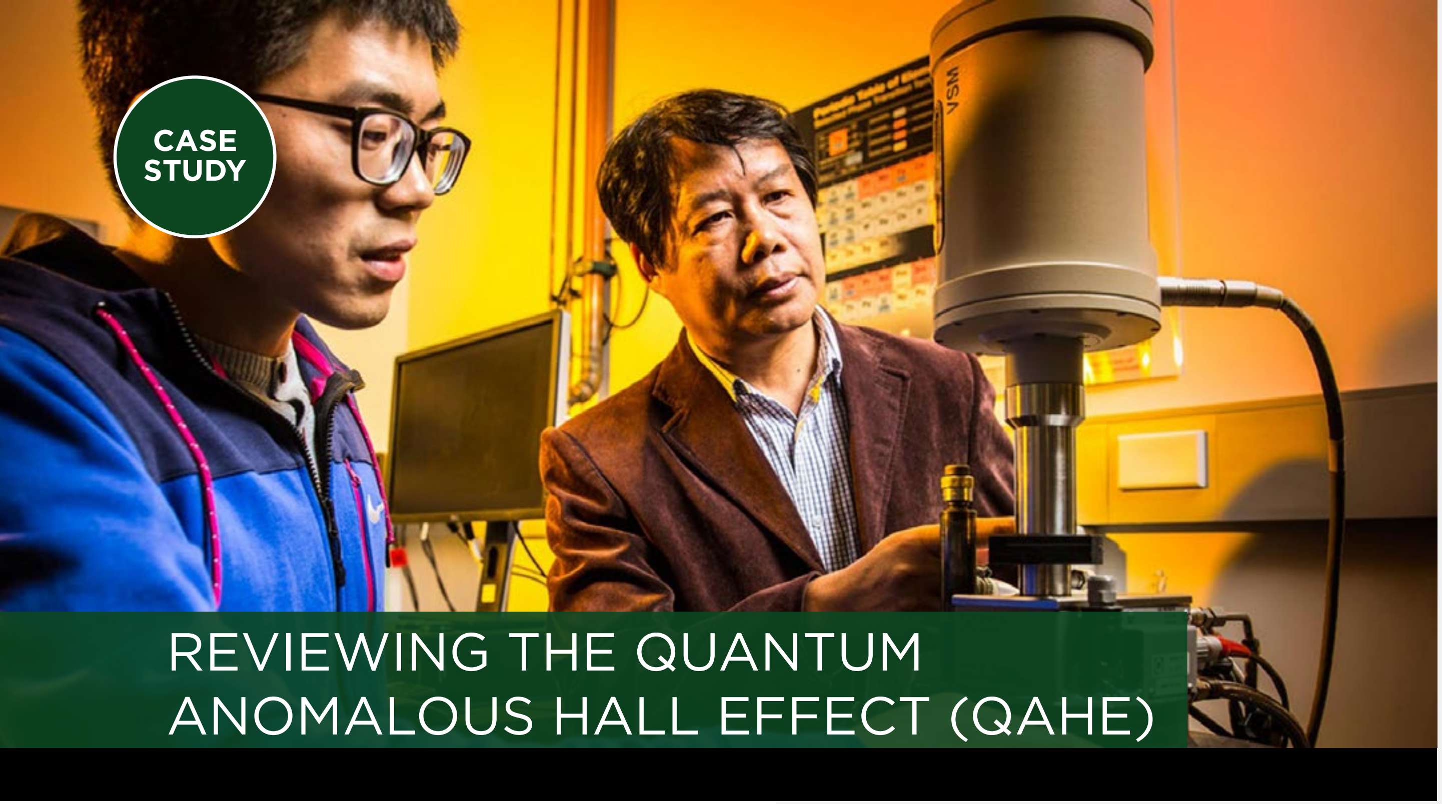
spin-gapless semiconductors A novel class of materials that bridge semiconductors and half-metals, zero-bandgap ferromagnetics

piezoelectric materials Materials that can convert mechanical stress or movement into electrical energy

ferroelectricty An electronic analogy to permanent magnetism

CASE STUDY

REVIEWING THE QUANTUM ANOMALOUS HALL EFFECT (QAHE)



> **Topological insulators conduct electricity only along their edges, where one-way ‘edge paths’ conduct electrons without the scattering that causes dissipation and heat in conventional materials.**
>
> Lead author, FLEET PhD student Muhammad Nadeem, UOW

A FLEET collaboration in 2020 reviewed the quantum anomalous Hall effect (QAHE), one of the most fascinating and important recent discoveries in condensed-matter physics, and absolutely key to FLEET’s mission to develop ultra-low-energy electronics.

It is QAHE that allows the zero-resistance electrical ‘edge paths’ in topological insulators and other quantum materials.

“Topological insulators conduct electricity only along their edges, where one-way ‘edge paths’ conduct electrons without the scattering that causes dissipation and heat in conventional materials,” explains the review’s lead author, FLEET PhD student Muhammad Nadeem (University of Wollongong).

Nadeem led the team of FLEET researchers from UNSW, Monash University and UOW who reviewed the fundamental theories underpinning QAHE, and applications.

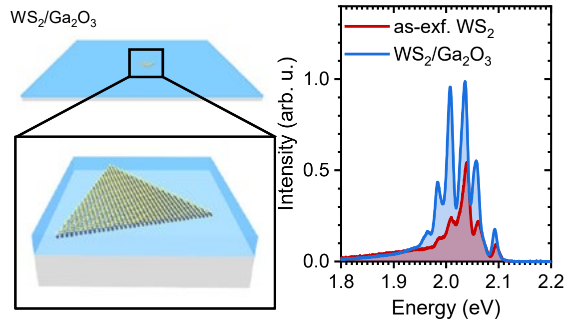
QAHE was first proposed by 2016 Nobel Prize recipient Prof Duncan Haldane (Princeton University) in the 1980s, although it subsequently proved challenging to realise QAHE in real materials. Magnetic-doped topological insulators and spin-gapless semiconductors are the two best candidates for QAHE.

QAHE describes an ‘unexpected’ (i.e. ‘anomalous’) quantisation of the transverse ‘Hall’ resistance, accompanied by a considerable drop in longitudinal resistance.

The driving force for this effect is provided by either spin-orbit coupling or intrinsic magnetisation.

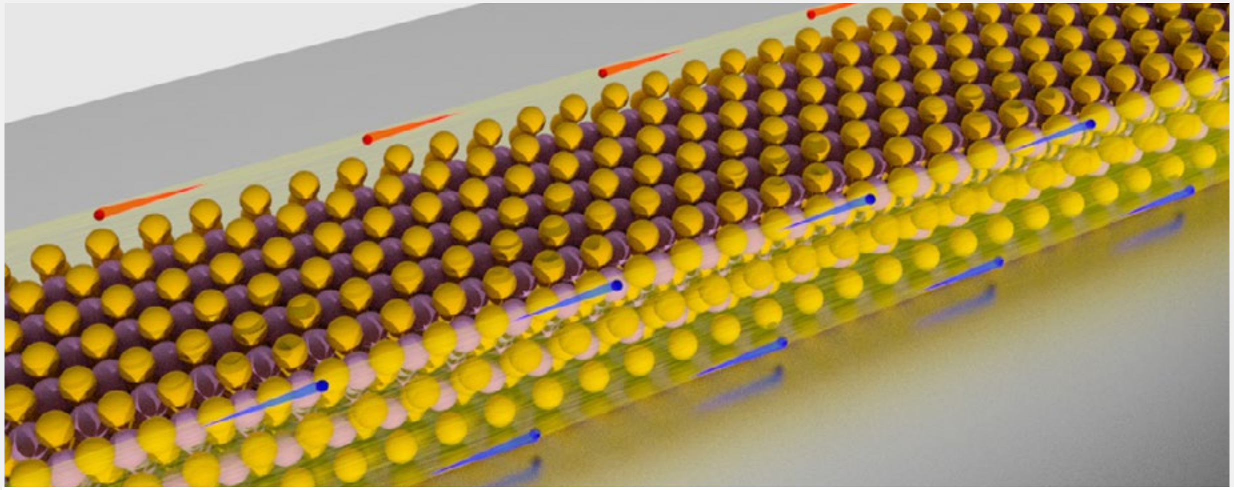
Researchers seek to enhance these two driving factors in order to strengthen QAHE and make topological electronics viable for room-temperature operation.

“It’s an area of great interest for technologists,” explains Prof Xiaolin Wang (UOW). “They are



Atomically-thin materials research at FLEET connects teams across the participating nodes. FLEET Research Fellow Dr Feixiang Xiang (UNSW) is shown visiting the labs at the University of Wollongong, with CI Prof Xiaolin Wang (UOW).

This research relates to FLEET milestones 1.15.
See page 13 of Strategic Plan



Demonstration of a material exhibiting QAHE, with the electrons going in opposite ways on opposite edges.

interested in using this significant reduction in resistance to reduce the power consumption in electronic devices."

Four models were reviewed that could enhance these two effects and thus enhance QAHE, allowing topological insulators and spin fully-polarised, zero-gap materials (spin-gapless semiconductors) to function at higher temperatures.

The study was published in ***Small*** in September 2020 **(see Publications)**

More at **FLEET.org.au/QAHE**

Back to Enabling Technology A: Atomically-thin Materials

Collaborating FLEET Personnel:

Professor Xiaolin Wang

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.

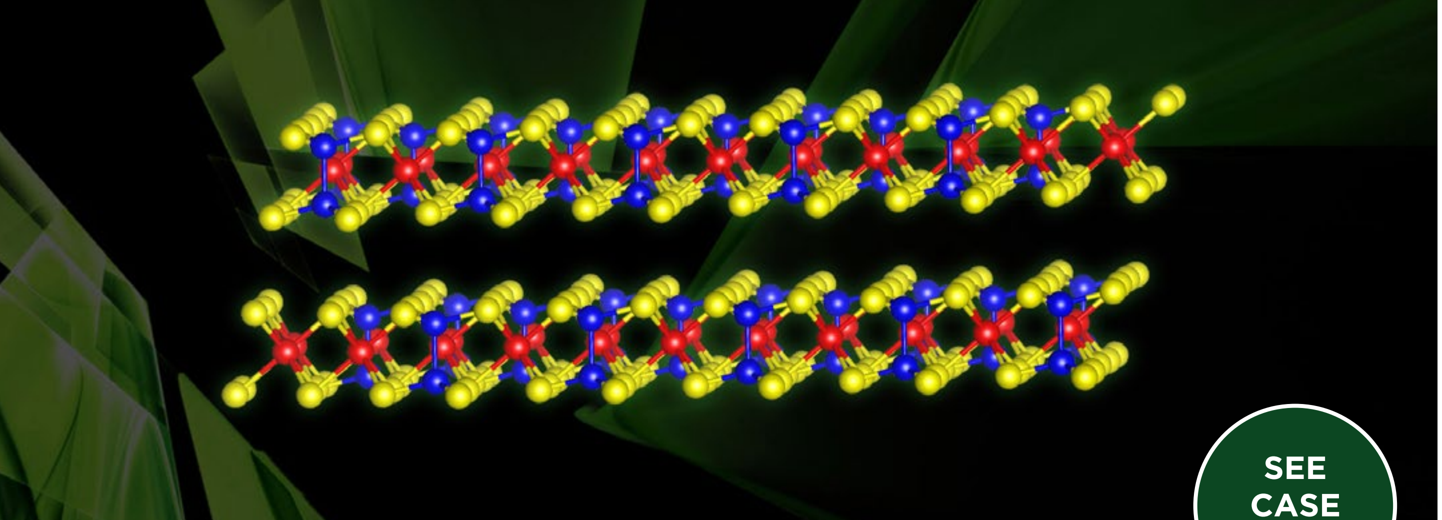
PhD Student
Muhammad Nadeem

Chief Investigator
Alex Hamilton

Chief Investigator
Michael Fuhrer

DID YOU KNOW...

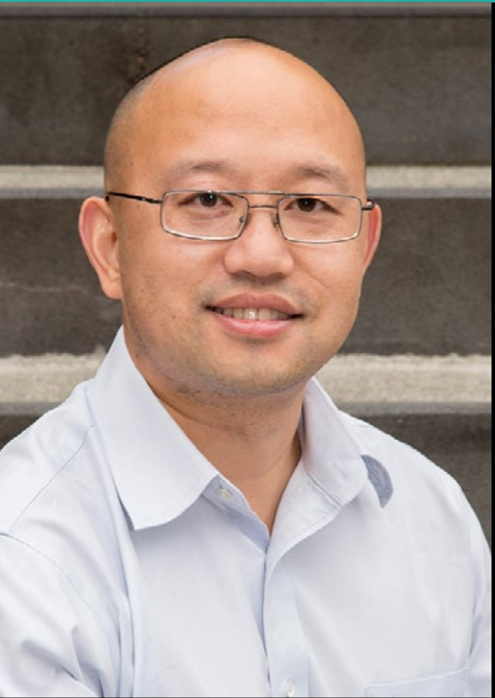
The Quantum anomalous Hall effect was first succesfully demonstrated in the lab by FLEET PI Prof Qi-kun Xue (Tsinghua), in 2013.



ENABLING TECHNOLOGY B

Nanodevice fabrication

SEE CASE STUDY



PROF LAN WANG

Leader, Enabling technology B,
RMIT University

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

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
3200+ citations
h-index 32 (Scopus)

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 links 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.

DID YOU KNOW...

Information and communication technology (ICT) now contributes as much to global warming as the aviation industry.

Yifang Wang, PhD student, University of New South Wales

IN 2021 FLEET WILL...

- Demonstrate electrically-tuned magnetic proximity effect in v**dW hetero-structures**
- Realise the **quantum anomalous Hall** effect in a **ferromagnetic** topological insulator
- Investigate spin transport in a topological material-based vdW hetero-structure
- Demonstrate electrical control of magnetism in 2D ferromagnets.

2020 HIGHLIGHTS

- Showed electrically-tuned interlayer coupling in vdW materials via a protonic gate, with potential application in various **vdW hetero-structure** devices (see case study)
- Demonstrated using gallium liquid-metal catalytic breakdown to form carbon–carbon bonds (the base of graphitic sheets) from organic fuels at room temperature
- Initiated a liquid-metals spin-off company with FLEET investigators Prof Kourosh Kalantar-zadeh and Dr Torben Daeneke
- Demonstrated theoretically that the topological quantum field-effect transistor (TQFET) can switch at lower voltage than a conventional transistor, overcoming “Boltzmann’s tyranny”, and developed design rules for 2D topological materials to be used in a TQFET; patent application submitted
- Established new fabrication technique for ultra-low-disorder artificial graphene in conventional semiconductor crystals
- Demonstrated robust negative differential resistance at room temperature in ultra-thin oxide ferroelectric superlattices

DEFINITIONS

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

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

van der Waals (vdW) hetero-structure A structure made by stacking layers of different van der Waals materials

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

ferromagnetic materials Material that can bemagnetised

CASE STUDY

USING PROTONS TO TUNE INTERLAYER COUPLING

Interlayer coupling in vdW material Fe_3GeTe_2 successfully increased by insertion of protons

FLEET led an international collaboration that demonstrated for the first time that interlayer coupling in a van der Waals (vdW) material can be largely modulated by a 'protonic gate', which injects protons into devices.

The discovery opens the way to exciting new uses of vdW materials, with insertion of protons an important new technique, now available for the wider two-dimensional (2D) materials research community.

Van der Waals materials, of which graphite is the most famous, are made of many 2D layers held together by weak, electrostatic forces.

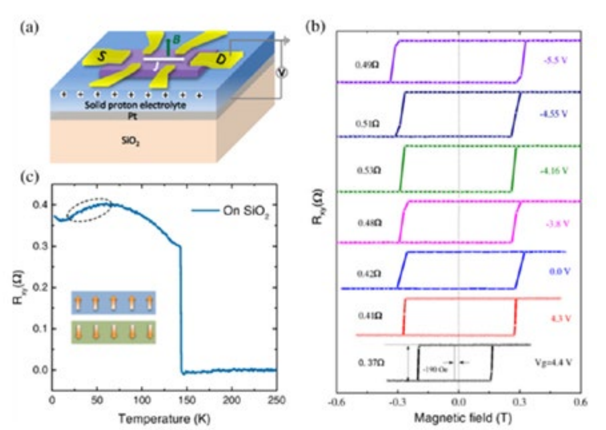
Individual layers of vdW materials can be isolated individually, such as the famous Scotch tape method of producing graphene, or stacked with other materials to form new structures.

> The same weak, interlayer forces that make vdW materials so easy to separate also limit these materials' applications in future technology.
>
> First author, FLEET Research Fellow Dr Guolin Zheng , RMIT

International nanofabrication collaboration: RMIT's Jian-zhen Ou and Lan Wang with Mingliang Tian (CAS High Magnetic Field Laboratory) and Xiaolin Wang (University of Wollongong)

"But the same weak interlayer forces that make vdW materials so easy to separate also limit these materials' applications in future technology," explains the study's first author, FLEET Research Fellow Dr Guolin Zheng.

Stronger interlayer coupling in vdW materials would significantly increase potential use in high-temperature devices utilising quantum anomalous Hall effect and in 2D multiferroics.



Hall-bar device on solid proton conductor used for measurements, and electrical response to changing temperature and magnetic field.

The new study demonstrated that coupling in a vdW material, Fe_3GeTe_2 (FGT) nanoflakes, can be largely modulated by a protonic gate, which injects protons into devices from an ionic solid.

With the increased number of protons among layers, interlayer magnetic coupling increases.

"Most strikingly, with more protons inserted at a higher gate voltage, we observed a rarely seen zero-field-cooled exchange bias with very large values," says co-author A/Prof Lan Wang.

The successful realisation of both field-cooled and zero-field-cooled exchange bias in FGT implies the interlayer coupling can be largely modulated by gate-induced proton insertion, opening the road to many applications of vdW materials requiring strong interface coupling.

The study was led by FLEET researchers at RMIT University, in an ongoing collaboration with FLEET partner organisation High Magnetic Field Laboratory, Chinese Academy of Sciences (CAS).

This research relates to FLEET milestone 1.7. **See page 13 of Strategic Plan**

More at **FLEET.org.au/ interlayer-coupling**

Back to Enabling Technology B: Nanodevice fabrication

DID YOU KNOW...

Van-der-Waals materials are those held together by vdW forces—weak bonding forces between nearby molecules. These same forces are what allows a gecko's feet to stick to the wall as it climbs.

Collaborating FLEET Personnel:

A/Prof Lan Wang

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.

Research Fellow

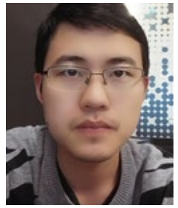
Guolin Zheng

PhD Student

Sultan Albarakati

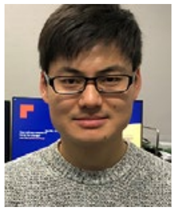
PhD Student

Meri Algarni



PhD Student

Cheng Tan



PhD Student

Jingyang Peng

PhD Student

Lawrence Farrar

Partner Investigator

Mingliang Tian

COLLABORATE
AT FLEET

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

- Research Collaboration
- Professional Collaboration
- Maintaining links during pandemic

Key data

Collaborative efforts

15 INTERNATIONAL TRIPS MADE FOR RESEARCH COLLABORATION

1 FLEET MEMBERS VISITING PARTNER ORGANISATIONS

8 NEW RESEARCH COLLABORATING ORGANISATIONS ESTABLISHED

2 VISITS BY INTERNATIONAL STUDENTS AND ECRs

5 VISITS BY INTERNATIONAL COLLABORATORS

30 NEW ORGANISATION LINKS FOR TRAINING AND OUTREACH ESTABLISHED

14 END USER RELATIONSHIPS

RESEARCH COLLABORATIONS

SEE CASE STUDY

FLEET's extensive network of 18 leading national and international research partners is key to fulfilling the Centre's mission.

HOSTING SCIENTIFIC MEETINGS (ICSCE10)

Supporting significant international and Australian science conferences

In January 2020 FLEET brought the 10th International Conference on Spontaneous Coherence in Excitonic Systems (ICSCE10) to Australia for the first time.

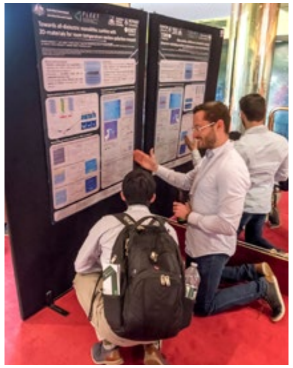
Continuing a 15-year history of meetings of the global scientific community interested in various quantum phenomena, ICSCE10 was hosted at the Arts Centre Melbourne amidst smoke storms resulting from one of the worst bushfire seasons in Australia's history.

ICSCE10 brought together more than 100 researchers studying spontaneous coherence in various physical systems including excitons, exciton-polaritons, cold atomic, and other quantum systems. These are topics closely related to FLEET's Research theme 2, exciton superfluids, and Research theme 3, light-transformed materials.

With almost 65% of conference attendees arriving from overseas, ICSCE10 enabled FLEET to strengthen our partnerships with existing international partners and develop links with new collaborators.

Co-chaired by FLEET theme 2 leader, Elena Ostrovskaya (ANU), and Timothy Liew, a FLEET collaborator from Nanyang Technological University, Singapore, ICSCE10's four-day program included 18 invited seminars, 50 oral presentations and 15 poster presentations.

International delegates were impressed with the iconic venue in Melbourne and the Indigenous-inspired conference dinner menu that showcased Australian native ingredients. Conference delegates also had fun with FLEET's periodic table Top Trump card game with quite a few requesting additional packs to bring back home to their friends and families.



HOSTING FLEET RESEARCH SEMINARS

Maintaining cohesion with Centre-wide colloquia and webinars

FLEET turbocharged our existing Centre-wide seminar series in 2020, with 10 research seminars – a significant increase from only four seminars in 2019.

Very aware of the importance of Centre cohesion without interstate travel and with many universities in lockdown, FLEET threw extra resources into monthly Zoom seminars, often overlapping with expanded 'journal club' meetings involving multiple interstate visitors.

Two seminars were held 'in-person' at FLEET nodes before Covid-19 lockdowns, with the remaining using Zoom video conferencing.

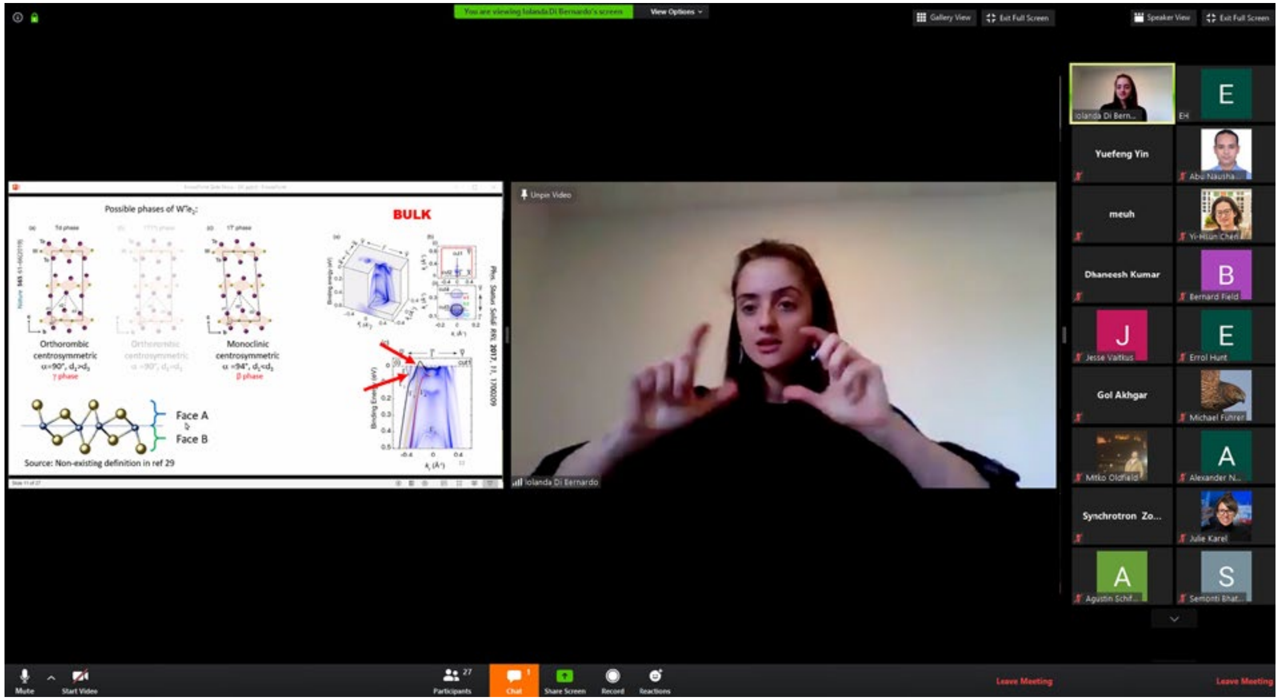
This year's seminar series focused on presentations from new Centre investigators. The series brought in external audiences by jointly holding the presentations with Centre partner organisations, including the MacDiarmid Institute (NZ) and ANSTO, and with other organisations such as the University of Newcastle School of Mathematical and Physical Sciences, Monash University School of Physics and Astronomy, and Materials Australia.

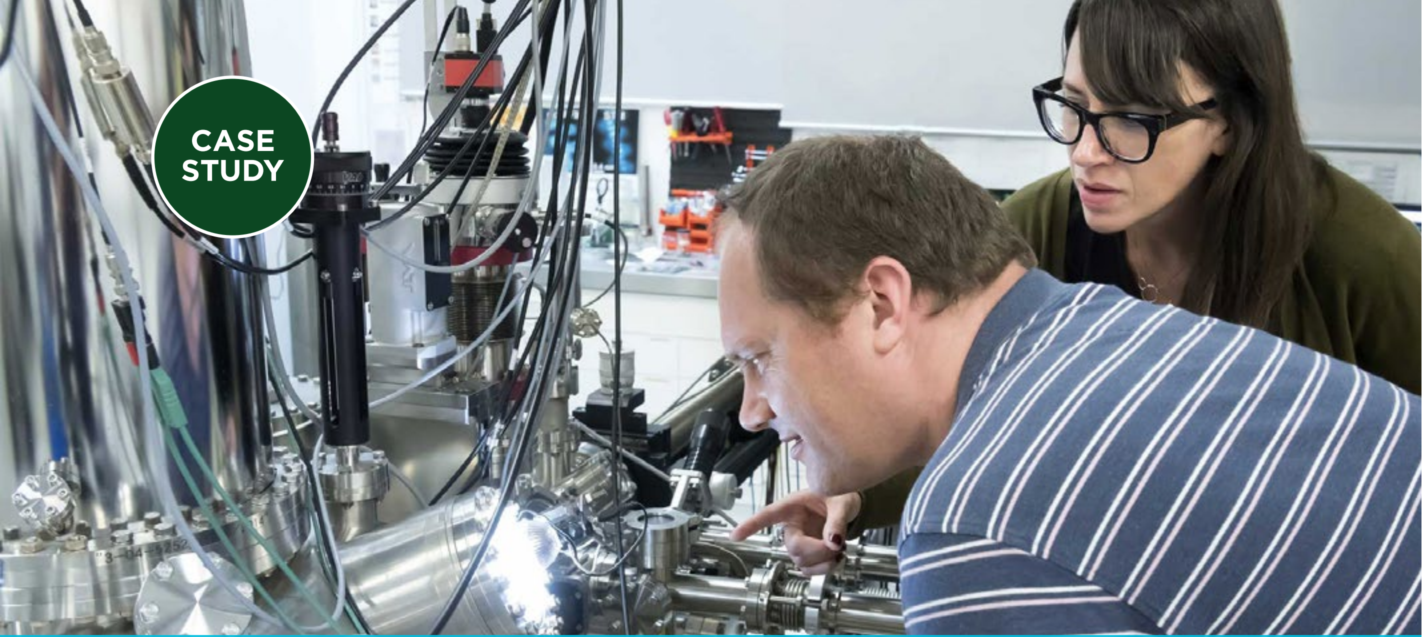
Unless confidential, unpublished information was shared, talks were recorded and shared via YouTube and social media for a wider audience.

The monthly seminars were scheduled in and around the new, fortnightly transpacific colloquia series and monthly Australian Institute of Physics (AIP) Australian Research Council (ARC) Centres talks.

> **Despite the difficulties of time shift with respect to overseas members, eg in Europe, I have been happy with FLEET's clear and friendly communication as well as the willingness to schedule online meetings that are mutually convenient time wise. In spite of the recent travel restrictions, the choice of online platforms for the annual meeting, facilitated a good, ongoing exchange of information and ideas.**
>
> FLEET Member survey

See FLEET.org.au for list of 2020 workshops and seminars





MAINTAINING INTERNATIONAL LINKS IN THE ABSENCE OF INTERNATIONAL TRAVEL

Left: Internal research links are key to FLEET's success. Before borders closed in early 2020, MacDiarmid's Simon Granville visited several FLEET nodes (and attended the AFLW).

> **FLEET provides opportunities to connect with other people within related research fields, provides resources for professional development, and provides a shared vision for research.**
>
> FLEET member survey

US-Australian transpacific condensed-matter talks

The temporary halt in international visits that traditionally spark and fuel research collaborations in 2020 pushed FLEET to find new ways to connect.

Some positives have surfaced amid the negative impacts of Covid-19 travel bans on science collaboration, including the expansion in videoconferencing allowing researchers from geographically isolated regions to connect.

Together with Centre partners at the Joint Quantum Institute (University of Maryland) and Monash University, FLEET inaugurated and hosted a new transpacific colloquium series to present novel development in condensed-matter and cold-atom physics.

To maintain and strengthen connections between physics communities in Australia and North America, the series hosted seven colloquia with speakers from Cornell, Stanford and Rutgers universities (USA), UNSW and Monash (Australia) and the University of Waterloo (Canada).

The colloquia covered topics from all FLEET research themes, including:

- Tuning electronic properties by tailoring 2D atomically-thin structures
- Understanding electronic structure topology through theoretical concepts
- Studying interactions between spin and orbital momentum
- Exploring techniques to study quasi-particle systems
- Two-dimensional superfluids.

The virtual series was not without challenges as the team navigated multiple time zones and daylight saving periods, all the while learning and mastering the art of Zoom video conferencing. The seven colloquia in 2020 attracted more than 180 Centre members and another 150 external participants.

The series represents one of 2020's 'silver linings': an improvement in the way the Centre operates that we intend to maintain going forward. Regardless of travel policies in 2021, the US–Australia Transpacific Colloquium series will continue.

Six additional speakers, from Caltech, Ohio State, McGill, Harvard and Columbia universities, are already lined up for the first half of the new year.

More at **FLEET.org.au/trans-pacific**

SEE CASE STUDY

PROFESSIONAL COLLABORATIONS

Building links with the Australian and international science communities

FLEET CONVERSATIONS

WORKING WITH OTHER SCIENCE ORGANISATIONS

Although 2020 posed unique challenges to in-person collaborations, FLEET proactively sought out opportunities to partner with other science organisations to further the reach of Centre-relevant science, advance equity issues and develop future leaders, for example:

- Working with the Australian Institute of Physics (AIP) to instigate and co-host a monthly series of talks spotlighting physics research at six different Australian Research Council (ARC) Centres – to continue in 2021
- Presenting FLEET science in a virtual briefing for the Royal Society of Victoria
- Pairing with ARC Centre for Engineered Quantum Systems (EQUS) to share development exercises on Wikipedia editing and gender/sexuality-diverse awareness
- Launching and co-hosting the new transpacific colloquia series with the Joint Quantum Institute (University of Maryland) and Monash University School of Physics and Astronomy
- Working with nine other ARC Centres on the Q&ARC video series, shared via social media
- Co-hosting talks with Materials Australia, the MacDiarmid Institute (NZ), ANSTO, Monash University School of Physics and Astronomy, and the University of Newcastle School of Mathematical and Physical Sciences
- Delivering the FLEET Future electronics Year-10 unit with John Monash Science School
- Running lab tours for local school students with Monash Tech School (pre lockdown)
- Working with professional organisation Materials Australia to deliver a lab tour and briefing (UNSW) and co-host a Zoom talk (Monash)
- Co-hosting a talk on future electronics with the Institute of Electrical and Electronics Engineers (IEEE), alongside the ARC Centre for Quantum Computation and Communication Technology (CQC^{2}T)
- Leadership mentoring with Women in Leadership Australia
- Industry-engagement and research-translation training with Ascend
- Highlighting ARC science at Australian Science Communicators conference with seven other Centres of Excellence.

CASE STUDY

SPOTLIGHTING ARC PHYSICS

Spreading the news about ARC funded research within the Australian physics community

FLEET pushed out the boundary of online talks, collaborating with the Australian Institute of Physics (AIP) to co-host a series of monthly public seminars highlighting Australian physics research.

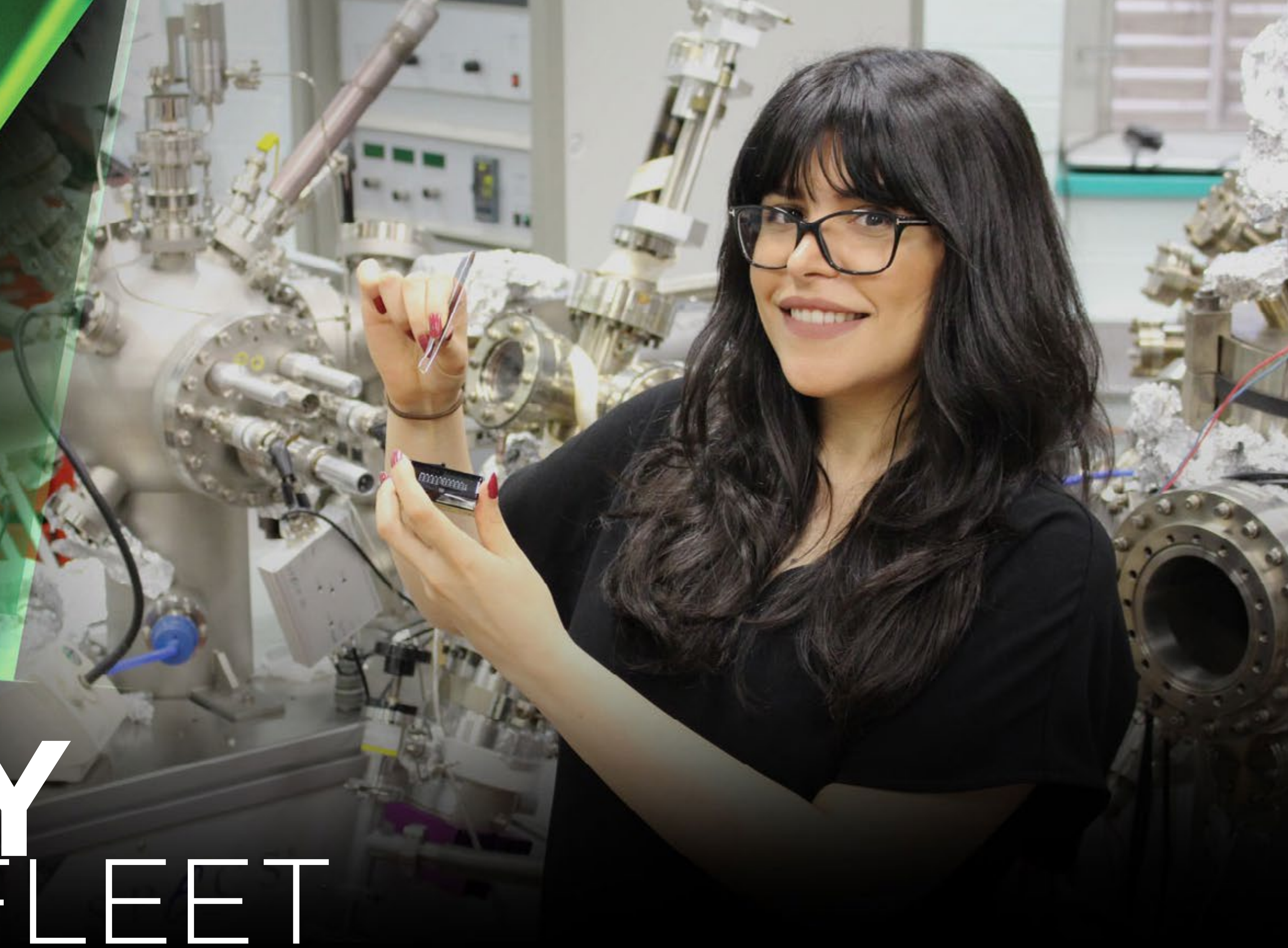
The new series throws the spotlight on a different ARC Centre of Excellence each month, with AIP members and others in the physics community joining over Zoom to hear about leading Australian research.

To date, almost 300 audience members have heard from six researchers, each spotlighting physics innovation from their own ARC Centre of Excellence (COE).

FLEET Partner Investigator Kirrily Rule (ANSTO) opened the series in May with the use of neutron scattering in developing novel materials for low-energy electronics. Her talk was followed by presentations from EQUS, the ARC COE for Gravitational Wave Discovery (OzGrav), CQC^{2}T, the ARC COE in Exciton Science and the ARC COE for Climate Extremes (CLEX).

This series will continue in 2021, with three presentations already lined up from the ARC COE for All Sky Astrophysics in 3 Dimensions (Astro 3D), the new ARC COE for Dark Matter Particle Physics and the ARC COE for Transformative Meta-Optical Systems (TMOS).

> **As the reality of COVID lockdowns became apparent in early 2020, and as FLEET quickly adopted the online format for internal and external webinars, it occured to us: why not invite other ARC Centres of Excellence to showcase the work carried out in their centres, and open up these talks to a wider community? The resulting talks have revealed the rich breadth and depth of world-leading research being carried out across Australia, and given a platform to COEs to connect and share their work with the broader physics community. All speakers have been passionate and engaging and truly inspirational. From a personal note, I have made connections with physicists in fields far removed from my own research – with possible collaboration ideas blossoming!**
>
> FLEET Partner Investigator
> Dr Kirrily Rule (ANSTO, Australian Institute of Physics)



EQUITY AT FLEET

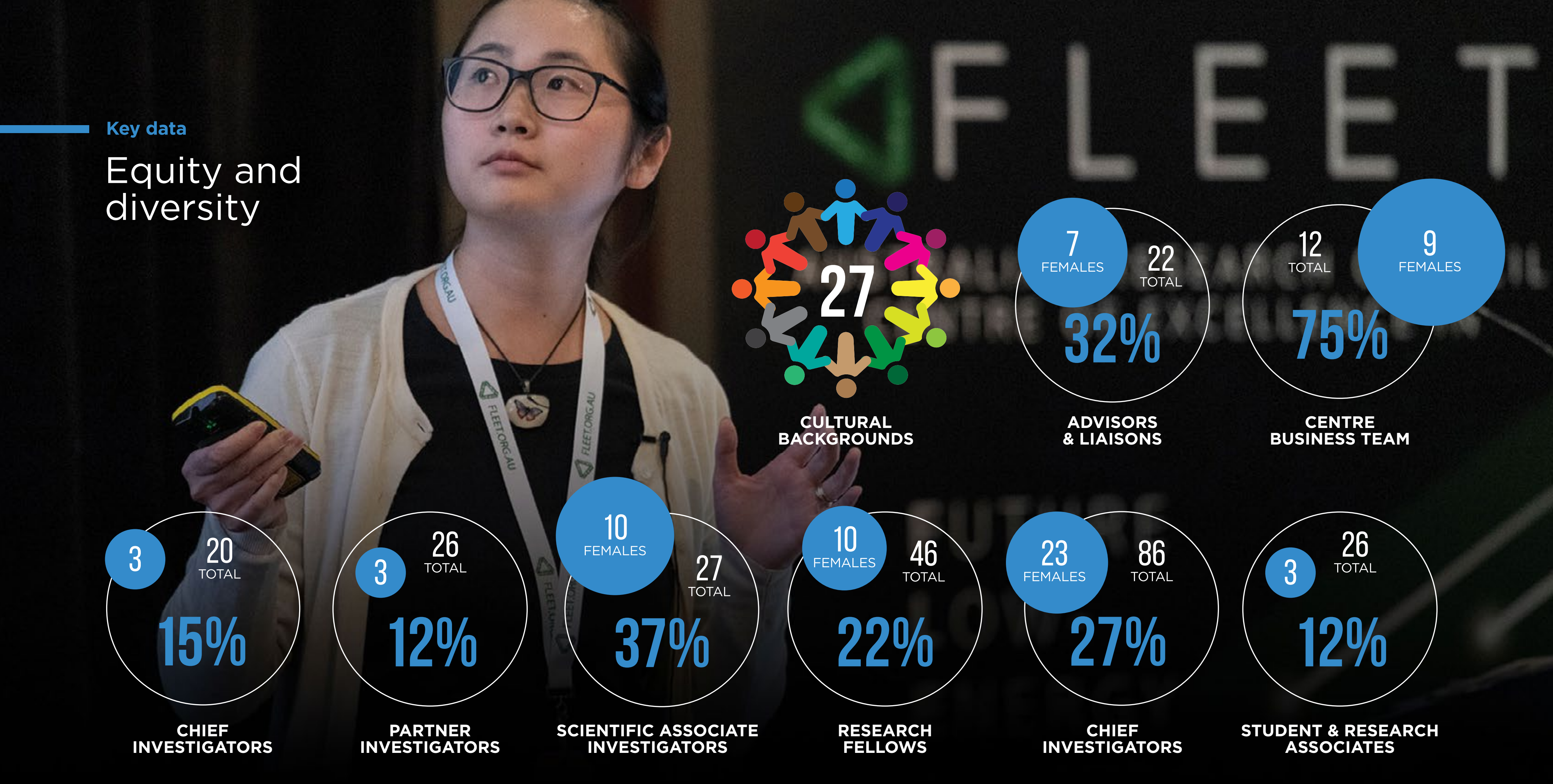
Equity and Diversity at FLEET

Women in FLEET

Listening to our members

Key data

Equity and diversity



27
CULTURAL BACKGROUNDS

7 FEMALES
22 TOTAL
32%
ADVISORS & LIAISONS

12 TOTAL
9 FEMALES
75%
CENTRE BUSINESS TEAM

3
20 TOTAL
15%
CHIEF INVESTIGATORS

3
26 TOTAL
12%
PARTNER INVESTIGATORS

10 FEMALES
27 TOTAL
37%
SCIENTIFIC ASSOCIATE INVESTIGATORS

10 FEMALES
46 TOTAL
22%
RESEARCH FELLOWS

23 FEMALES
86 TOTAL
27%
CHIEF INVESTIGATORS

3
26 TOTAL
12%
STUDENT & RESEARCH ASSOCIATES

27% **FEMALES IN FLEET** (OUT OF 239 CENTRE MEMBERS)

27% **FEMALE RESEARCH STUDENTS AND ASSOCIATES**

33% **FEMALE EARLY CAREER RESEARCHERS**

Note: data for indigenous and people with disability unavailable

EQUITY AND DIVERSITY AT FLEET

Women are under-represented in science, particularly in physics. In this regard FLEET is no exception. We are taking steps to improve this.

Diverse teams do better science. By improving our performance with respect to gender equity and diversity, we are not only doing what's fair, we are also creating a more effective research team.

A priority for FLEET in 2020 was increasing representation of women at higher levels. We have achieved this, increasing female representation among the Centre's advisers and liaisons who guide FLEET management and scientific directions from 21% in 2019 to 32% now.

Furthermore, FLEET has also attracted new female investigators to join the research team, which has increased female representation among investigators from 17% in 2019 to 22% now. However, we are still below our overall target of 30% representation of women at all levels.

SEE CASE STUDY

Fixing the infamous 'leaky pipeline' involves both retaining female researchers and recruiting more. While we have successfully retained women in 2020 (with the help of Women in FLEET scholarships and Fellowships), Covid-19 restricted our ability to recruit, and this will be a significant focus in 2021.

FLEET's recruitment in its first two years drew from the existing pool in physics, material science and engineering, which unfortunately have a relatively low percentage of women.

FLEET's Women in FLEET Fellowships and strategic grants have allowed the Centre to increase the percentage of women at early-career researcher (ECR) and associate investigator levels, to above the average in physics.

The Centre's Women in FLEET scholarships for higher-degree research students will assist ECRs at the beginning of their science career.

Redressing historical disadvantages for women in physics provides many complex challenges, and our actions must cut across all of FLEET's strategies and policies. Internal surveying of experiences and attitudes (see case study) helps maximise the chance of success for these changes.

See more at FLEET.org.au/equity

FLEET'S NEW FEMALE INVESTIGATORS

Esther Levy

Joanna Batstone

Karen Livesey

Karina Hudson

Rebekah Brown

Tamalika Banerjee

LISTENING TO, AND RESPONDING TO, OUR PEOPLE

To improve equity, foster diversity and inclusion, and remove barriers to create and maintain a respectful culture within the Centre, it's vital we listen to, and understand, our members.

The FLEET Suggestion Box (intranet-based) allows members to provide feedback about the Centre in general or raise any matters that need management attention.

FLEET has also implemented a new procedure and support for any members who have witnessed or experienced unacceptable behaviour.

With unprecedented impacts from Covid-19 in the way we work and live, Centre management has focused on maintaining connection and ensuring members are aware of available support and remote working resources.

FLEET also ran a specific 'pandemic and you' survey to get members' feedback on how Covid and surrounding issues were affecting them, and to ask how FLEET could better support members.

We found that members were affected in many different ways, both positive and negative. Some found benefits in working from home, including better work–life balance, more time to spend with family, and fewer distractions and interruptions.

However, many others struggled, particularly members with caring responsibilities and those doing experimental projects who have been unable to access labs.

The survey confirmed that our students and early-career researchers (ECRs) were worried about future career prospects due to the reduced availability of research positions. They were also worried about their individual competitiveness due to lab closures and reduced productivity.

> **FLEET provides an inclusive encouraging environment and supports its members by providing great opportunities via workshops, trainings, interactions etc.**
>
> Anonymous Centre member

To help bridge the gap and ensure that students are well placed to transition into the next phase of their research training, FLEET created PhD write-up scholarships for students affected by Covid restrictions, allowing them to continue writing-up papers and/or finish projects after submitting their PhD and while waiting for examiners' reports (see case study).

A key component of developing successful strategies is to measure and track progress. FLEET's annual survey helps us understand the quality and impact of current initiatives. Of the 34% of members who responded:

- Over 90% found their workplace inclusive and respectful, up from 80% in 2019
- 80% were aware of FLEET equity and family-friendly policies and initiatives, down from 90% in 2019
- Over 90% agreed that FLEET values equity and diversity, the same as 2019

Listening to our people

- 87% were aware of opportunities FLEET provides to help make it easier to be a woman in STEM, down from 96% in 2019
- Almost 90% felt they are encouraged to progress their career goals within FLEET and take up career development opportunities, the same as 2019.

Members suggested numerous ideas to help increase the Centre diversity and inclusiveness, such as:

- Creating Women in FLEET-like scholarships and fellowships for other minority and under-represented groups
- Promoting interactions and networking among different diversity groups through social events
- Running training in how to lead a diverse team
- Highlighting and celebrating different cultures within the Centre
- Developing outreach programs to reach specific minority groups, such as Indigenous Australians and people with disabilities, potentially starting with school students.

One member suggested that FLEET should strive for a tomorrow when the Centre no longer need an Equity and Diversity Committee. A worthy goal!

On the type of opportunities that FLEET can provide to help members build their careers, members have noted workshops on identifying transferrable skills, career planning and industry engagement.

FLEET IS:

- Raising members' awareness through training on equity, diversity and inclusion topics
- Sharing information on diversity and inclusion resources at FLEET nodes for members
- Fostering an inclusive and equitable workplace culture, including support for members with family responsibilities
- Establishing career-support initiatives for women in FLEET
- Operating a women-specific mentoring network
- Increasing diversity among all cohorts of researchers:
  - Attracting high-performing students via Women in FLEET Honours and PhD scholarships
  - Retaining female researchers in STEM via Women in FLEET Fellowships.

IN 2020 FLEET HAS:

- Increased representation of women at higher levels
- Surveyed our members on Covid-19 and equity issues
- Increased the visibility of women in FLEET in outward-facing communications
- Run career training for PhD students affected by Covid-related issues
- Invested in future female science leaders, with training under Women in Leadership Australia
- Extended Women in FLEET funding to higher degree by research (HDR) student scholarships
- Instigated write-up scholarships for PhD students
- Provided an avenue for easy feedback about any experiences of an exclusive environment or discrimination.

IN 2021 FLEET WILL:

- Expand focus of equity programs to include Indigenous Australians, LGBTQI, cultural diversity and people with disabilities
- Build on learnings from 2020 to implement best-practice flexible, accessible work models
- Continue write-up scholarship support for PhD students impacted by Covid-19
- Implement more priories informed by 2020 member survey (eg, celebrating diversity, building understanding of different cultures, building awareness of inappropriate behaviour)
- Further implement FLEET-wide culture awareness
- Work with Diversity Council Australia to provide training on equity, diversity and inclusion.

SEE CASE STUDY

LOOKING AFTER OUR PEOPLE IN 2020

Covid-19 and related restrictions did not hit everybody equally, with research showing that early-career researchers and in particular young women, have been disproportionately affected.

In response to this, and informed by a specific 'pandemic and you' survey of our members, FLEET:

- Ran career training for early-career researchers who will be job hunting post pandemic
- Offered write-up scholarships for Honours and PhD students. See the Case Study.
- Reduced KPI requirements for hours of outreach, so as not to put undue pressure on people already struggling
- Incorporated a mental-health and wellbeing panel into the Centre's annual workshop, with key members frankly and honestly sharing their experiences and challenges, successfully encouraging others to also share.

EQUITY-RELATED TRAINING

To help FLEET become more aware of unconscious bias and other barriers to cultural and gender diversity and inclusion, each year every FLEET member must attend at least one training workshop or 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.

The FLEET website, intranet and newsletter provide links to resources and opportunities available at individual nodes, as well as those provided by FLEET partner the Diversity Council Australia (DCA), which provides a wide toolkit of knowledge programs, research, practical tools and events.

Centralised equity training in 2020 included:

- Wikipedia – editing training focused on minority scientists
- LGBTIQ+ – awareness panel
- Modelling gender gap in STEM: Session in FLEET annual workshop
- Women in Leadership Australia leadership training. See the Case study.

This included valuable Ally-network training on lesbian, gay, bisexual, transgender/gender diverse, intersex and queer (LGBTIQ+) ally and gender issues via universities or other organisations. Individual members also chose training in transgender awareness, LGBTIQ+ inclusion, the #IncludeHer movement, making flexibility work, respectful workplaces and diversity fatigue.

WOMEN IN FLEET

To encourage the participation of young women in scientific research and attract high-performing female scientists, FLEET has added Women in FLEET (WiF) scholarships for research students to existing WiF fellowships.

Making use of both investigators' research funds and Centre equity and diversity funds, scholarships are open to students who identify as female and are accepted into an Honours or PhD program to work with FLEET investigators.

To date, FLEET has awarded two WiF Honours scholarships and five WiF PhD top-up scholarships to seven outstanding students from diverse backgrounds.

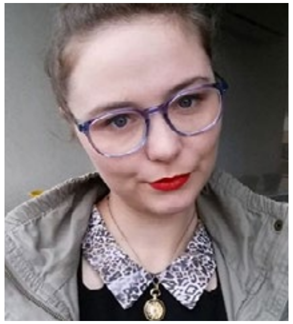
"I enjoyed my time working with FLEET because it has deepened my understanding in an essential topic to the progress of technology. I thought I would never be capable to work in an environment full of such brilliant minds," says Jessica Alves, the first recipient of the WiF Honours scholarship. Jessica is now pursuing a PhD program working on three-dimensional laser lithography at Queensland University of Technology.

The most recent recipient of a WiF PhD top-up scholarship is Maedehsadat Mousavi, a materials science engineer with a background in nanotechnology. Maedehsadat joined FLEET from Iran following a master's degree in pharmaceutical engineering and is currently investigating liquid-metal-assisted synthesis and applications of topological insulators for her PhD project with Chief Investigator Prof Kourosh Kalantar-zadeh at UNSW. Still in her first year of the PhD program, Maedehsadat has already co-authored three research publications and has another first-authored paper under preparation.

Left: Jessica Alves, Monash University - first recipient of the Women in FLEET Honours scholarship

SEE CASE STUDY

WOMEN IN FLEET SCHOLARSHIPS

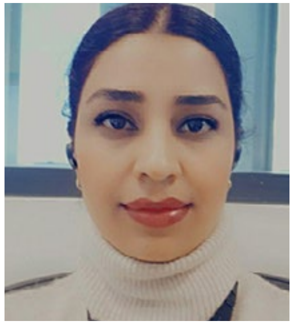


Abigail Goff

Coco Kennedy

Jessica Alves

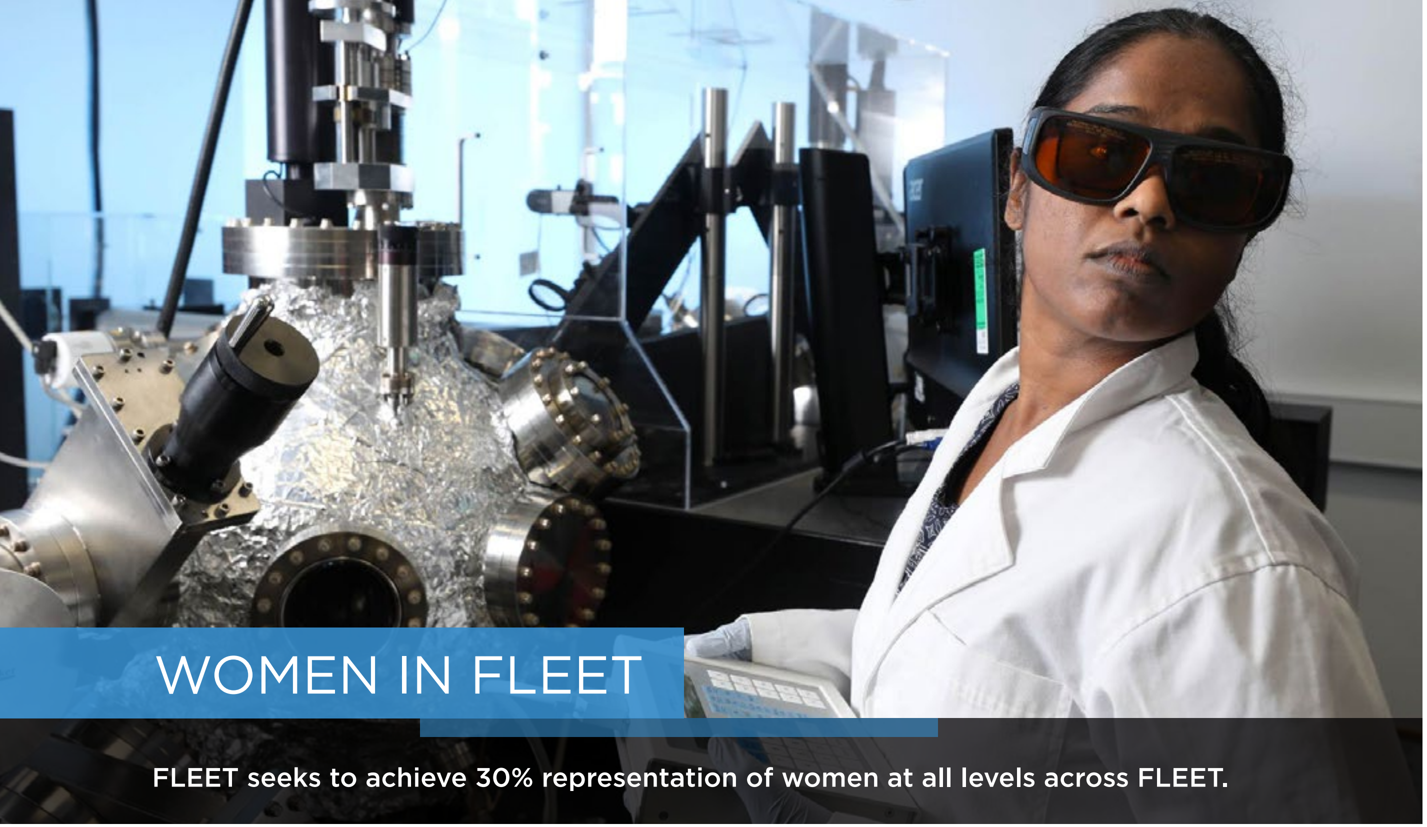
Lina Sang



Maedehsadat Mousavi

Patjaree Aukarasereenont

Yifang Wang



WOMEN IN FLEET

FLEET seeks to achieve 30% representation of women at all levels across FLEET.

> **It's evident that FLEET responds to survey feedback, and I thank the team for this. It is very reassuring to work for such a Centre.**
>
> FLEET member survey

To begin moving towards 30% female representation across all levels, the Centre needed innovative approaches that would allow us to begin 'shifting the dial'. One successful initiative was FLEET's Women in FLEET Fellowships, offered in multiple locations and across all fields of study in the Centre.

The women-only Fellowships have allowed the Centre to increase the representation of women to above the average in fields such as physics and materials science.

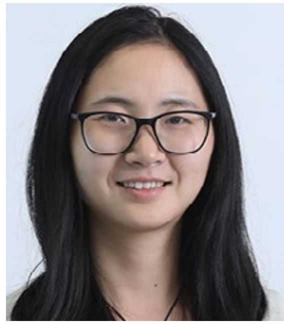
This was the first such initiative for a Centre funded by the Australian Research Council.

See more at FLEET.org.au/women-in-fleet

> **Women in FLEET recruitment process outside of the usual university system was a bold move.**
>
> FLEET member survey

WOMEN IN FLEET FELLOWS

Dr Semonti Bhattacharyya
Monash University



Dr Peggy Qi Zhang
UNSW

Dr Iolanda Di Bernardo
Monash University

SEE CASE STUDY

CASE STUDY

SUPPORTING FUTURE SCIENCE LEADERS

FLEET is committed to developing Australia's next generation of science leaders, and to improving on the current imbalance of women in higher positions in science, technology, engineering and maths (STEM).

> **Leading Edge by WLA, was an amazing 6 month programme (funded by FLEET) meant for guiding women in their path to leadership. I learnt a lot during that time, had the opportunity to discuss with some wonderful ladies. It made me learn a lot about myself.**
>
> FLEET WLA participant

Career support for women in FLEET works towards both of these goals, providing an environment in which early-career women can thrive, progress and grow into capable and confident leaders.

Efforts to boost the number of women scientists in leadership positions will also have long-term benefits as future generations are inspired by the increasing number of role models.

FLEET has been seeking new training opportunities that complement existing research and professional development programs. To date, FLEET has successfully secured 11 partial scholarships from Women and Leadership Australia (WLA), with a total value of $19,000, to enable 11 FLEET women to participate in the WLA Leading Edge program. These scholarships are highly competitive, and each organisation can only submit a limited number of applicants. The residual program fee is supported by FLEET's equity and diversity initiatives fund.

"The Leading Edge program provides practical management and leadership training, with a holistic approach to building skills and mindset for successful leadership," says Centre Chief Operating Officer Dr Tich-Lam Nguyen. "Seven FLEET women have participated in the 2020 program, and it has truly enabled our members to transition into confident and motivated leaders."

Two of the seven, Dr Dianne Ruka and Dr Charlotte Hurry, have recently taken on leadership roles as managers for two newly-funded ARC industry transformation research training centres. While FLEET has ended up losing two exceptional staff from the Centre business team, the industry has gained two highly capable STEM leaders.

In addition, FLEET has also acquired two new activities that will enhance the Centre's current training and outreach programs:

- Leading Edge alum Vivasha Govinden, a FLEET final-year PhD student from UNSW, developed and implemented a virtual outreach program designed for primary school students (see case study).

- Charlotte Hurry has developed a ‘future leaders workshop’ to guide ECRs and students to proactively manage their future careers through action planning and goal setting, which will be implemented in 2021.

Additionally, participants have also transferred what they have learnt from the Leading Edge to the FLEET community by coordinating a training workshop on general leadership skills, sharing their personal experiences on the program.

“The WLA program is really amazing! Throughout the four-month program, I stayed connected till the last minute and was always looking forward to the next module each fortnight,” says Vivasha Govinden. “I learnt something new in each session. The workshop not only made me aware of my shortcomings but it also showed me how to embrace weaknesses and work on them. It has definitely made me a more confident person and I now look forward to challenges that help me improve myself.”

Following notable outcomes from the 2020 Leading Edge cohort, FLEET has invested additional support for four more Centre women to participate in the 2021 program.

“As a new postdoctoral researcher, I want to develop skills in effective student supervision and lab management,” says Dr Peggy Schoenherr. “I see interpersonal communication skills as a cornerstone to a successful working culture and my career, particularly working in a male-dominated environment where it’s sometimes hard to be heard and to convey confidence. I think the Leading Edge program would provide me with the tools and training I need to advance and do well in these work conditions.”

See more at FLEET.org.au/QAHE

WLA SCHOLARSHIPS

Cecilia Bloise

Charlotte Hurry

Chi Xuan Trang

Dianne Ruka

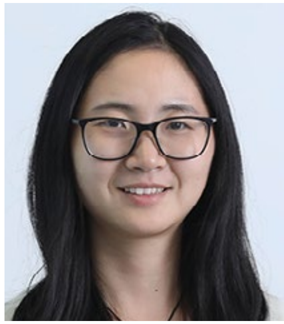
Hareem Khan

Iolanda Di Bernardo

Maria Javaid

Maryam Boozarjmehr

Peggy Qi Zhang



Peggy Schoenherr

Vivasha Govinden

WRITE-UP SUPPORT TO BRIDGE THE 2020 GAP

> The write-up scholarship gives me a chance to focus on finishing up planned publications while looking for a postdoc role without the financial burdens. Thank you so much FLEET!
>
> Dhaneesh Gopalakrishnan
> FLEET PhD student

Covid-19 and related restrictions have affected people in different ways, with adverse effects falling disproportionately on early-career researchers, particularly those with caring responsibilities, and those doing experimental projects who have been unable to access labs.

FLEET's 'pandemic and you' survey confirmed that our students worried about future career prospects, due partly to a potential post-2020 reduction in research positions. They also worried about their individual competitiveness due to lab closures and reduced productivity.

To help bridge the gap and ensure that students are well placed to transition into the next phase of their research training, FLEET created PhD write-up scholarships for students affected by the restrictions in response to Covid-19.

Up to three months' support allows students to continue writing-up papers and/or finish projects after submitting their PhD and while waiting on examiners. To date, four students have accessed the FLEET write-up scholarships.

"You have no idea what a relief the scholarship is for me!" says FLEET PhD student Hareem Khan. "Due to lab closures, I have not been able to finish off some lab work for some collaborative papers. And Covid-19 restrictions have really drawn out the end part of my PhD. I eventually submitted my thesis in July but it has been very stressful trying to fulfil revisions for a Nature Communications publication while home-schooling a seven-year-old, caring for a 10-month-old baby as well as searching for a postdoctoral position".

Hareem used her write-up scholarship to finish off two papers that were under review, and is currently in the process of drafting two additional publications. She has recently secured a postdoctoral position within the CSIRO energy division.

FLEET alum Dr Hareem Khan used FLEET's write-up scholarship to finish off papers under review, compensating for lab closures and home-schooling.

EDUCATION
AT FLEET

- Research impact training
- Mentoring
- Post-pandemic career training

Key data

Educational developments

8
RESEARCH WORKSHOPS AND CONFERENCES ORGANSIED

17
RESEARCH SEMINARS AND COLLOQUIA HELD

7
RESEARCH AND PROFESSIONAL DEVELOPMENT WORKSHOPS

1349
TOTAL CUMULATIVE NUMBER OF CENTRE MEMBERS ATTENDING TRAINING WORKSHOPS

512
TOTAL CUMULATIVE NUMBER OF NON-CENTRE MEMBERS ATTENDING TRAINING WORKSHOPS

131
OUTREACH ACTIVITIES INVOLVING FLEET MEMBERS

4
MENTORING PROGRAMS

CASE STUDY

YOURFORUM - SO YOU'RE GRADUATING IN A PANDEMIC, WHAT NEXT?

Building ECRs' career skills to approach a post-pandemic job market with more confidence

> **Covid-19 presents a massive disruption to the academic workforce. PhD students and early career researchers are worried about their future career prospects inside academia and confused about their options outside the university walls.**
>
> Prof Inger Mewburn, ANU

Around 35 PhDs and other early-career researchers (ECRs) from FLEET and partner organisation the MacDiarmid Institute (NZ) took the opportunity to learn how to take control of their future in these uncertain 'post pandemic' times, and to gain a better understanding of the job market (both in academia and industry), in a targeted, one-hour workshop from 'the thesis whisperer'.

A/Prof Inger Mewburn applies her ANU team's research on the post-PhD job market to:

- Enhance understanding of the changed academic job market, analysing effects of hiring freezes and travel restrictions
- Increase awareness of career opportunities in industry — which sectors are looking for research talent?
- Help ECRs and PhDs approach the non-academic job market with more confidence.

This was the first FLEET–MacDiarmid Institute trans-Tasman workshop.

The Young Researchers Forum, aka YouRforum, was created by FLEET Chief Operating Officer Dr Tich-Lam Nguyen (then at the Monash Centre for Atomically Thin Materials) to provide opportunities for young STEM researchers to network, discuss research ideas and practice their professional skills.

DID YOU KNOW...

Among respondents to FLEET's 'pandemic and you' survey, concerns about getting their next job was the highest concern listed (almost 50% of respondents)

SEE CASE STUDY

BUILDING FUTURE SCIENCE LEADERS

FLEET ensures that our young researchers are prepared for future success – wherever their career takes them.

The Centre currently supports 65 higher degree by research (HDR) students and 45 postdoctoral researchers with another 21 research affiliates working on FLEET projects and invited to Centre training, workshops and events.

FLEET connects its researchers with internal and international networks, for example, offering research internship programs at partner organisations.

We are fortunate that FLEET early-career researchers (ECRs) have welcomed leadership roles within the Centre, including:

- Initiating **'remote' outreach projects**
- Seeking out and coordinating development training for ECRs and students
- Running internal leadership and skills training (leadership, Blender animation software, Illustrator graphics package)
- Chairing Centre governance committees.

FLEET TRAINING PROGRAMS IN 2020

- Blender science-animation training, run by Research Fellow Dr Iolanda Di Bernardo
- Illustrator graphics training, run by Dr Dianne Ruka
- How to write a scientific paper, run by Chief Investigator Prof Nagy Valanoor
- **Building leadership skills** (WLA, Leading Edge)
- Got PhD what's next – **graduating in a pandemic**, in partnership with FLEET partner, the MacDiarmid Institute
- Ascend **research impact and industry engagement**
- Effective presentations and Wikipedia-editing skills, with the ARC Centre for Engineered Quantum Systems (EQUS)
- Annual workshop tutorials/colloquia (graphene, research translation, quantum-based metrics, artificial intelligence (AI) and data science for social good, exciton-polaritons, equity modelling).

In addition, FLEET organised a number of training sessions around **equity and diversity awareness** and Centre members presented updates on their research in the series of **monthly FLEET live-streamed seminars**.

Members were also funded by FLEET to pursue their own, individual training needs, with the assistance of a small ECR-coordination team that sought out relevant opportunities. Individual training included grant writing, science communication, paper-writing and presentation skills, software (Excel, Premiere, Illustrator, Python), sign language, data science, LinkedIn and career skills.

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.

Two mentoring models are offered:

- Individual, goal-oriented mentoring, where members are individually matched to a mentor within FLEET based on their needs, for example, guiding application for promotion, grant writing or providing career advice
- Group mentoring via training sessions, for example, on manuscript preparation, grant writing, scientific presentation and research leadership.

Participation of senior members as mentors is high, with 90% of our chief investigators being a mentor. However only 25% of scientific associate investigators and 10% of partner investigators are mentoring FLEET ECRs and students, and we would like to improve this.

Participation of our members as mentees also needs improvement: only 51% of FLEET students and 43% of research fellows are mentees in a FLEET mentoring program.

FLEET continues to improve its mentor program, guided by surveying participants.

I have grown professionally, I have got acquainted with a mentor that I can completely trust, who has enormous experience to share, and has a balanced outlook on things. She is also very frank, and she appreciates my small victories.

Semonti Bhattacharyya (mentee)

SEE CASE STUDY

Mentees have typically indicated their mentor relationship enabled a distinct social connection – often outside the tightly-bonded network of the physics discipline – with whom they could share experiences. Their mentor provided balance and perspective on their career, problems in their own research and on bigger picture issues affecting their lives.

Constructive feedback from participants has suggested more formal guidance and training for mentors and mentees might help build more genuine and effective relationships and improve the intended outcomes, such as expanding mentee skill sets and career decision-making.

FLEET MEMBERS ACCESS A NUMBER OF MENTORING PROGRAMS, INCLUDING:

- External mentor programs (7 members)
- Early-career researcher mentoring (45 members)
- Industry mentoring (2 members)
- Academic mentoring (11 members)
- Women in FLEET mentoring (13 members).

I've found it valuable to have a mentor who can indicate whether research-related issues I am going through are normal or not.

Bernard Field (mentee)

It is good to share experiences. The FLEET mentor program is a good support network – particularly in a year like 2020.

Kirrily Rule (mentor)

MEMBERS INVOLVEMENT IN FLEET MENTORING PROGRAMS

	Mentees	Mentors
Chief investigators	40%	90%
Partner investigators		10%
Scientific Associate investigators	20%	24%
Research Fellows	43%	26%
PhD Students	51%	

CASE STUDY

SKILLING UP OUR PEOPLE: RESEARCH IMPACT AND INDUSTRY ENGAGEMENT

While researchers are typically familiar with communicating their research to others in their scientific community, it is not always easy for them to link their research outputs to outcomes benefiting society.

- **Who would be interested in my research?**
- **Who would benefit from it the most?**
- **How can I pursue high-impact research?**
- **How does research translation work?**
- **If I've developed some cool intellectual property, where would I start with industry engagement?**
- **How do I effectively 'sell' the value of my research in an award application/grant/job interview?**

FLEET recognises that researchers need to be able to effectively demonstrate the value of their work to the world outside academia. Indeed, FLEET needs to do this ourselves!

With the goal to train researchers to better articulate benefits of their research, and translate their research outputs to research impact, FLEET funded two teams on an intensive coaching program, called Ascend, that provides tools and training on industry-engagement skills.

Six PhD students, the Centre communications coordinator and the chief operating officer formed two teams, 'Low-energy electronics' and 'Semiconductor revolution', that embarked on a ten-week boot-camp with three other project teams from La Trobe and Victoria universities.

The two FLEET teams explored how they might bring these visions to life:

- What if future growth in computing was not limited by electric power availability?
- What if we had sustainable, affordable electronics?

Each and every member had to step thoroughly outside their comfort zone by initiating conversations with various industry stakeholders. Interviews were designed to help the teams understand the problem, clarify their purpose and test their solution.

Ascend provides tools to help teams understand and articulate big problems that are worth solving, validate assumptions about the problem and communicate the purpose of their research.

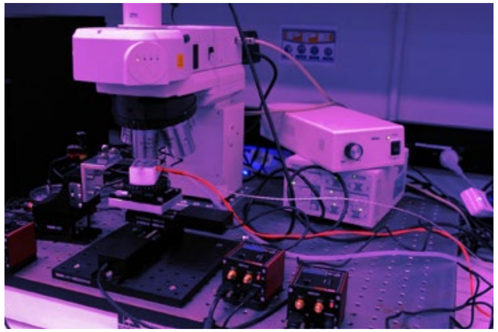
"We've learnt how to refine our pitches to fit the target audience," says participant Hareem Khan. "Each target industry has a huge ecosystem map, and it's important to identify all the stakeholders in the system and to tap into our immediate networks – starting broadly and then focusing on particular target markets."

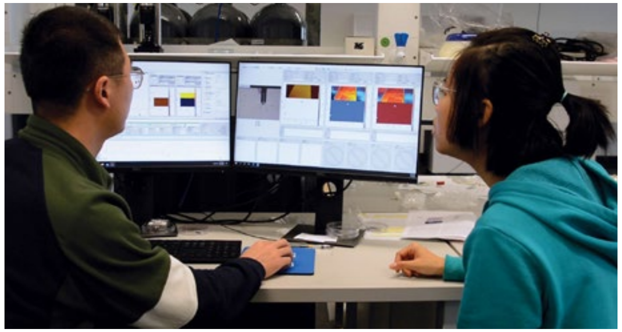
"The network we gained through our mentor and his connections was extremely valuable to help us develop our insights from different industries," says Jesse Vaitkus.

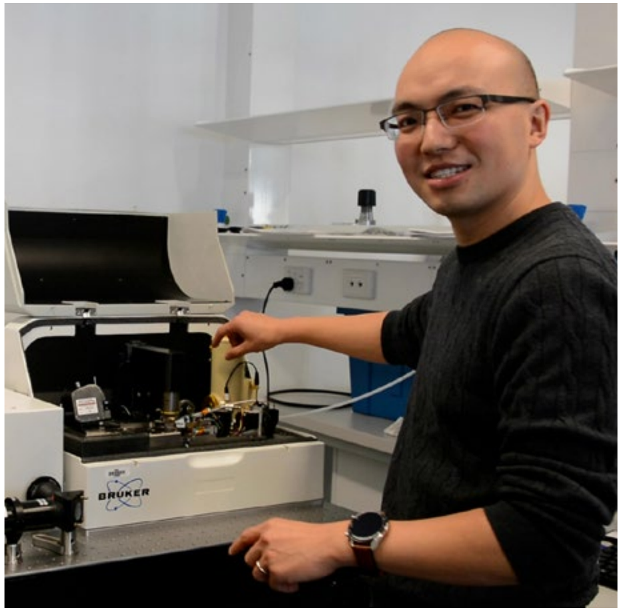
"Any research that aims for impact should be controlled by market pull and not the technology. We learned that it is much easier to make things people want than make people want things," says Abigail Goff. "In order to determine what people want or need, we need to interview them. Interviews are key! They allow us to develop a network to learn things about our market and to tailor our product to customers."

Skilling up our people

> **The network we gained through our mentor and his connections was extremely valuable to help us develop our insights from different industries.**
>
> Jesse Vaitkus
> FLEET PhD student, RMIT University







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.

- Putting FLEET science on the map
- Hands-on virtual outreach
- Online annual workshop

Key data

Stakeholder engagements

2906

AVERAGE MONTHLY NEW USERS VISITING FLEET.ORG.AU

952

HOURS SPENT ON **OUTREACH**

2214

PUBLIC AUDIENCE REACHED THROUGH **OUTREACH ACTIVITIES**

89

HOME SCIENCE ACTIVITIES DEMONSTRATED TO DATE

131

OUTREACH ACTIVITIES INVOLVING FLEET MEMBERS

1710

SCHOOL STUDENTS REACHED THROUGH **OUTREACH ACTIVITIES**

271

SCHOOL TEACHERS ENGAGED

BLOGS	97
PRESS RELEASES	34
MENTIONS IN ONLINE MEDIA	488
NON PEER REVIEWED ARTICLES	18
PRINT ARTICLES	20
RADIO INTERVIEWS	6

1138

TWITTER FOLLOWERS 239 NEW

644

FACEBOOK FOLLOWERS 48 NEW

15,106

VIEWS OF FLEET YOUTUBE CHANNEL

5894

AVERAGE MONTHLY UNIQUE PAGE VIEWS

SEE CASE STUDY

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

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

DID YOU KNOW...

Up to 75% of future jobs will require skills in science, technology, engineering and maths (STEM). Yet school participation in science is in decline

> **It is extremely helpful to have a dedicated outreach person who arranges a wide range of opportunities for FLEET members to participate, and also provides support: resources, coaching, advice, etc. Ie, not just leaving members to 'fend for themselves'.**
>
> FLEET member survey

2020: A CHALLENGING YEAR FOR OUTREACH!

In 2019, after a remarkable achievement in reaching over 10,000 students, FLEET voluntarily raised its outreach target from 200 students to 2000 students, 50 teachers to 75 teachers and 2000 public members to 5000 public members.

And then Covid happened …

However, despite the unique challenges that Covid imposed on face-to-face outreach, cancelling public events and banning in-class or in-lab visits, FLEET is extremely proud of our achievements in science outreach in 2020.

Almost to our own surprise, we met our voluntarily-increased schools outreach target, reaching 1665 students (83% of target) and 263 teachers (351%).

We almost met our extremely ambitious target of 20 hours spent by every FLEET member on outreach activities, after offering members a comprehensive suite of 'virtual' outreach activities to choose from.

Engaging with students

We reached over 2200 members of the public (44% of target), despite the lack of public events from March onwards.

In, addition, FLEET members:

- Created their own home-science experiments in lockdown
- Crafted a DIY lightboard for science outreach videos
- Quickly adapted to online delivery of the John Monash Science School (JMSS) Year 10 FLEET science unit
- Designed a new system for virtual in-class outreach
- Fine-tuned skills for science outreach and communication, including Blender animation, Wikipedia editing, perfecting the science pitch
- Pitched to 16 new industry contacts as part of Ascend program
- Arranged virtual lab tours for students to 'visit' Swinburne, UNSW and Monash University.

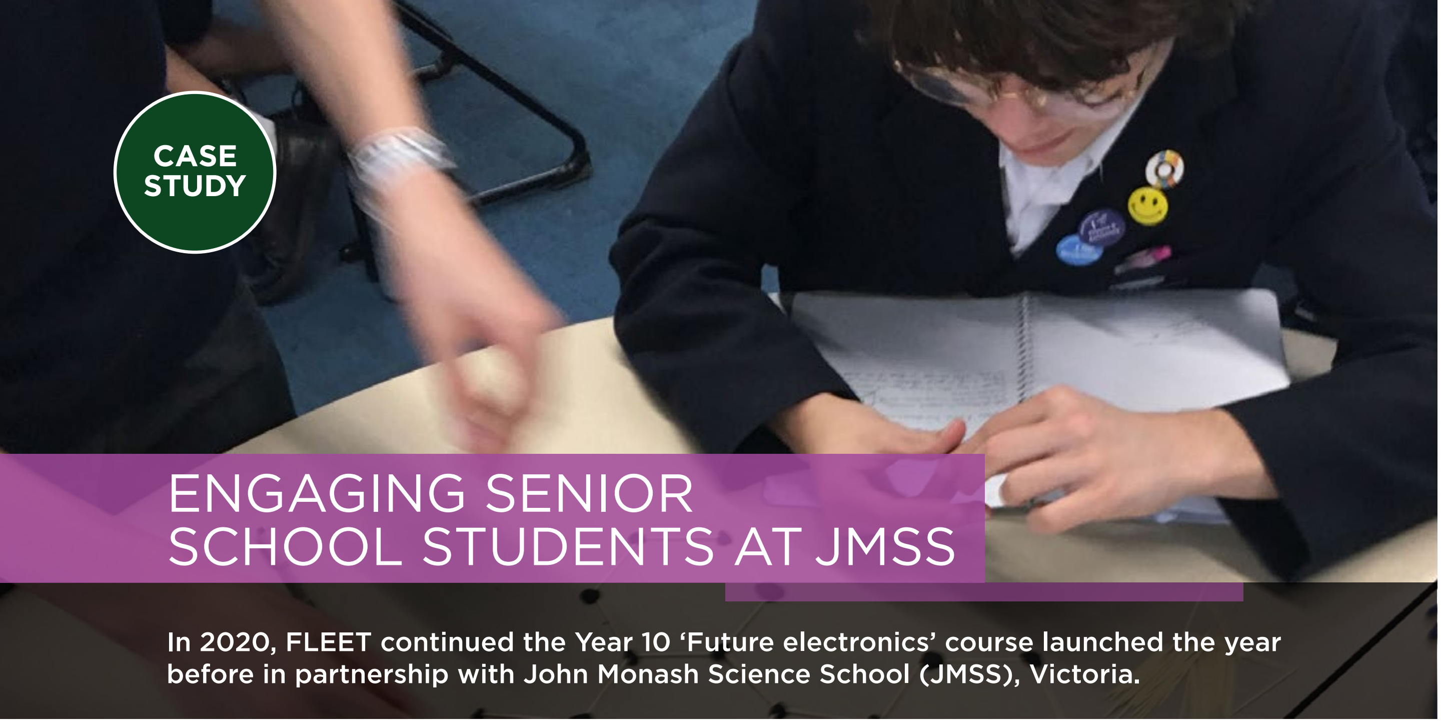
VIRTUAL LAB TOURS

In the absence of in-house lab tours to introduce school students to working labs and researchers, in 2020 FLEET developed a series of 'virtual lab tours', of varying levels of interactivity:

- Show-and-tell lab tour via webcam for John Monash Science School (JMSS) students of FLEET laboratories at UNSW in Sydney (materials science), and Swinburne in Hawthorn (cold-atom optics)
- UNSW experimental lab introductions for Open Day
- Monash University Materials Science and Engineering and School of Physics and Astronomy lab videos for Open Day
- Three-dimensional 'walk through' of the New Horizons lab, Monash
- Virtual in-school outreach featuring FLEET members in the lab dialling in to guide hands-on experiments in class.

> **While 'traditional' outreach activities this year were not really possible, members really rose to the challenge in identifying new ways in which we could reach the broader community. I was so impressed and inspired by what folks came up with!**
>
> Dr Julie Karel,
> Chair, FLEET Outreach Committee

SEE CASE STUDY



CASE STUDY

ENGAGING SENIOR SCHOOL STUDENTS AT JMSS

In 2020, FLEET continued the Year 10 'Future electronics' course launched the year before in partnership with John Monash Science School (JMSS), Victoria.

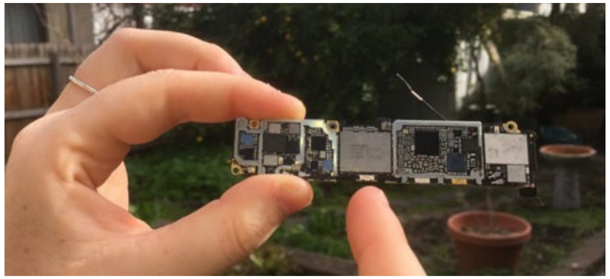
> **I liked learning about the different areas of physics FLEET is involved in. The guest speakers provided a nice insight into applications of the topics we learn in class and how they apply to real-life situations.**
>
> JMSS student

As well as covering the history of semiconductors, Moore's Law and computing, the course introduces quantum physics at an intuitive level (with minimal maths) and expands on this fundamental understanding to explain complex, useful quantum states such as superfluids and topological materials.

This year, FLEET and our teacher partners faced the additional challenge of Covid-19 restrictions on in-class visits, rewriting content on the go to accommodate talks delivered over Zoom, with particular challenges for hands-on class exercises.

FLEET members helped to develop and deliver the courses, building valuable skills within the Centre, and exposing students to a much more diverse cast of physicists than the thoroughly 'pale, stale and male' 19th-century gentlemen whose names and biographies are traditionally taught in physics classes.

Centre lab researchers also delivered 'virtual lab tours', with a show-and-tell tour via webcam, showing JMSS students at Clayton around the FLEET



The A9 chip, removed from an iPhone 6S, has 2 billion transistors: concrete demonstration of Moore's law for students

laboratories at UNSW in Sydney (materials science), and Swinburne in Hawthorn (cold-atom optics).

Within the overriding structure of putting FLEET science into context, content taught covered the spectrum from fundamental atomic and quantum physics to applied computing and technology, including:

- An atomic understanding of electrical conduction
- Function and construction of transistors, and their use in increasingly-complex Boolean logic circuits
- The role of binary numbers in digital computing
- Quantum science, including wave-particle duality and uncertainty
- Superfluids and excitons
- Topology and topological materials
- Ultra-cold atomic physics
- Quantum computing (with the help of the Australian Research Council Centre of Excellence for Quantum Computation and Communication Technology, CQC^2T)
- Graphene and other two-dimensional (2D) materials.

This diversity meant that most student were able to find at least one topic they were passionately interested in.

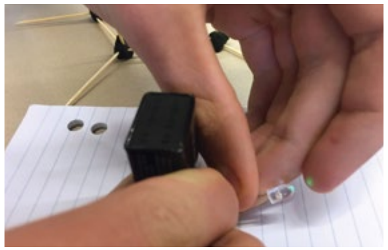
Without the need for wholesale rewriting, FLEET and JMSS will repeat the unit in 2021 and expand to at least one other school.

CASE STUDY

REMOTE OUTREACH THAT'S ALSO HANDS-ON

FLEET scientists seeking new, creative ways to do science outreach found a silver lining in Covid-19 restrictions: they actually improved the experience for students.

A team of FLEET-UNSW PhDs and early-career researchers (ECRs) was able to bridge 2020's Covid restrictions to safely engage a classroom of students with virtual, but hands-on science.



Hands-on experiments switched on LEDs (or introduced probing questions: "why did the LED blow?")

Colour-mixing experiments delighted younger students

Led by PhD student Vivasha Govinden and node administrator Cecilia Bloise, the team engaged via Zoom with students from kindergarten through to Year 7 at two schools: one in Sydney and another in Melbourne.

After a short talk outlining the background of energy use in computing, FLEET's virtual outreach team engaged the students with some of FLEET's homegrown home-science experiments, which the students were able to perform in class.

Instructions for the home-science experiments were fleshed out behind the scenes by other FLEET members, exercising their own science communication muscles in a difficult year for public outreach.

"I think there is a silver lining in this," says FLEET's Vivasha Govinden. "I really like the idea of having the kids doing the science themselves, rather than watching us do demonstrations (as we would have a year ago, for example), as it boosts their confidence, rather than leaving them as passive observers".

DID YOU KNOW...

FLEET details 89 hands-on 'home science' experiments, which kids and parents can do in the home or class with easily-accessible materials

> **A unanimous 'WOW!' came from all four classrooms when the LED light lit up, just by connecting two thick pencil tracks to a 9 V battery!**
>
> FLEET's Dr Peggy Schoenherr (UNSW), student activities guide

By performing the experiments themselves, the students realise they can do science too. And that is an extremely effective way to evoke a passion for doing science.

"A unanimous 'WOW!' came from all four classrooms when the LED light lit up, just by connecting two thick pencil tracks to a 9 V battery," says FLEET Research Fellow Dr Peggy Schoenherr (UNSW), who helped guide Victorian students through the activities.

Some of the students found alternative ways to light the LEDs, discovering for themselves the joy of scientific, curiosity-driven experiment.

Jotting down their hypotheses – 'what do you think is happening?' – and their conclusions, the class was stepped through a taster of the scientific method.

"This outreach program made the kids realise that you don't necessarily need sophisticated laboratory equipment to do science," says Vivasha Govinden. "With the help of simple household items such as matches and candles, you can do science yourself!"

SHARING FLEET RESEARCH: COMMUNICATION

Communicating FLEET research and events, internally and externally

> **FLEET has a dedicated team for publicising research outputs online and via social media, and a broad range of communication channels available.**
>
> FLEET member survey

FLEET's communications functions include:

- Internal communication to maintain a cohesive Centre
- Informing the Australian public of the benefits being gained from research funded by the Australian Research Council (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
- Building the transferable communications skills of FLEET members.

FLEET faced 2020's unique challenges to internal and external communication by:

- Facilitating casual, unstructured intra-Centre discussions via the Slack online-discussion platform (also integrated with the annual workshop) and weekly 'tearoom' catch-ups
- Significantly increasing the number of internal Centre seminars, from four to ten
- Instigating weekly email digests to members and affiliates to summarise Centre and relevant events, including Zoom links
- Experimenting with online virtual-meeting platform iSee to allow organic discussions and poster sessions, including at the Centre's annual workshop
- Co-hosting Trans-pacific series of condensed-matter talks to maintain links between US and Australian physics communities
- Instigating and facilitating Australian Institute of Physics–ARC Centre series of talks
- Seeking out opportunities to partner with other science organisations in delivering 'Covid safe' content
- Promoting FLEET write-ups via increased numbers of press releases and research blogs.

Also see the Centre's 2020 remote-outreach achievements.

SEE CASE STUDY

RESEARCH BLOG

FLEET puts significant effort into web-based blog posts, sharing research news across the Centre, along with outreach, training, equity and other news.

The fresh, regularly updated content from FLEET's research blog provides the content feeding the Centre's social media, providing compelling content for followers on Twitter, Facebook and LinkedIn.

Short descriptions linking to blog posts in the Centre's monthly newsletter also provide broad news to members, affiliates and stakeholders.

The same content, pushed out to online science platforms, supports the Centre's online media mentions and drives researchers' Altmetric rankings.

FLEET news is avalable online and over 34,000 people visited in the last year.

FLEET's blog forms an extremely effective channel:

- Promoting members' research
- Celebrating members' achievements
- Highlighting Centre engagement with partners and the wider community.

FLEET succesfully uses mainstream media, university and partner communication teams, and online science platforms to communicate Centre research results widely – to the public as well as science peers. The Centre has twice voluntarily increased the 'media mentions' target, after exceeding the original goal by a factor of more than 10.

In 2020, with many members concentrating on writeup, the Centre put extra effort into sharing the news of this research. In total, 34 FLEET stories had full press-release distribution (compared with 13 last year), with these driving the bulk of the Centre's 557 media mentions in 2020, and improving researchers' visibility to potential global collaborators.

Online and social-media news functions

> **A silver lining of Covid pandemic travel restrictions was to force quick expansion of virtual meetings and other online tools. I expect we will use some of these online tools long into the future, as they've helped us meet more frequently, with less of an environmental footprint, and potentially the ability to directly interact with a broader cross-section of the public, as well as other scientists.**
>
> Dr David Cortie,
> FLEET Communications Committee Chair

CASE STUDY

ONLINE ANNUAL WORKSHOP

With strict Covid-19 restrictions across much of FLEET's Australian nodes, and eliminating international visitors, the decision was made to hold the Centre's 2020 annual workshop entirely online.

By this time, Centre decision-makers were well aware of 'Zoom fatigue'. People spending many hours on Zoom each week were finding interacting only via computer screen to be dis-engaging, and surprisingly exhausting.

In response, FLEET's annual workshop alternated between morning sessions conducted in the now-traditional Zoom format, with extended breaks for recharge between talks, and afternoon poster sessions on the new iSee virtual-meeting platform.

"While Zoom works well for 'formal' plenaries and webinar talks, it has its limits," says Communications Committee Chair Dr David Cortie. "We found the new iSee platform to be ideal for poster sessions and informal meetings, allowing spontaneous, 'organic' conversations and break-out rooms in a virtual environment, which can be engaging and refreshing."

The new, Australian-developed iSee platform uses a gaming-graphics engine to create a 3D virtual environment of a conference venue, or lecture theatre, allowing participants to move around and reinforcing 'normal' interactions through realistic spatial audio (i.e. people standing further away are quieter), supporting multiple conversations in the same space.

This is done while maintaining the face-to-face 'webcam' screenshot of participants familiar from Zoom.

In addition, iSee provides the ability to set up virtual spaces, complete with posters and PowerPoint presentations.

iSee has its origins in the Smart Services Cooperative Research Centre which was jointly funded by industry and the Australian Government.

"Adopting the iSee platform for our meetings was an ambitious goal," says David Cortie. "We knew the unfamiliar navigation of a virtual platform could trouble some members, particularly anyone unfamiliar with 'first person' type computer gaming."

"But we felt that the pros outweighed the cons, and by investing time in this emerging platform, we are helping support a new way to communicate online in the future."

"We used a hybrid combination of Zoom for the main talks, and iSee for the poster sessions and social events at our annual meeting."

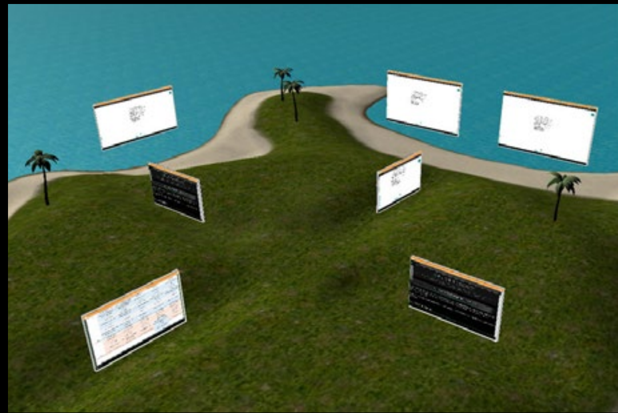
Despite technical challenges, and navigating the (previously unknown!) phenomenon of virtual motion sickness for some members, FLEET was satisfied with the iSee experiment.

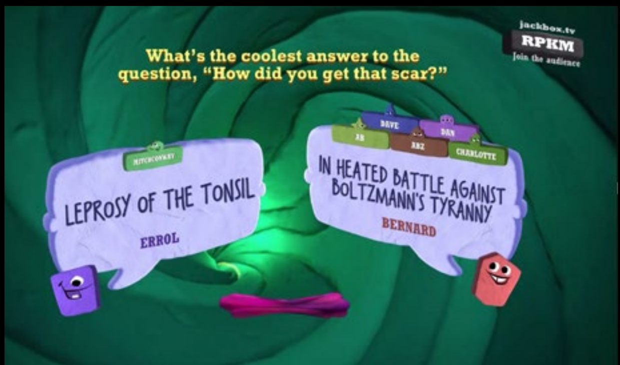
"We should be pushing the envelope of communications to some degree," explains David. "iSee, Slack, and the regular weekly tearoom were all examples of new communications initiatives that we trialled to see what worked and what didn't."

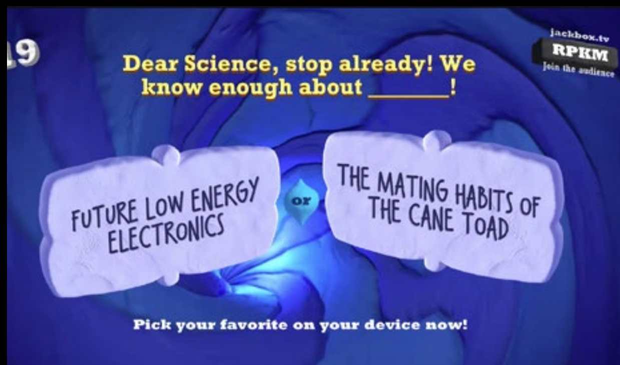
The annual workshop included:

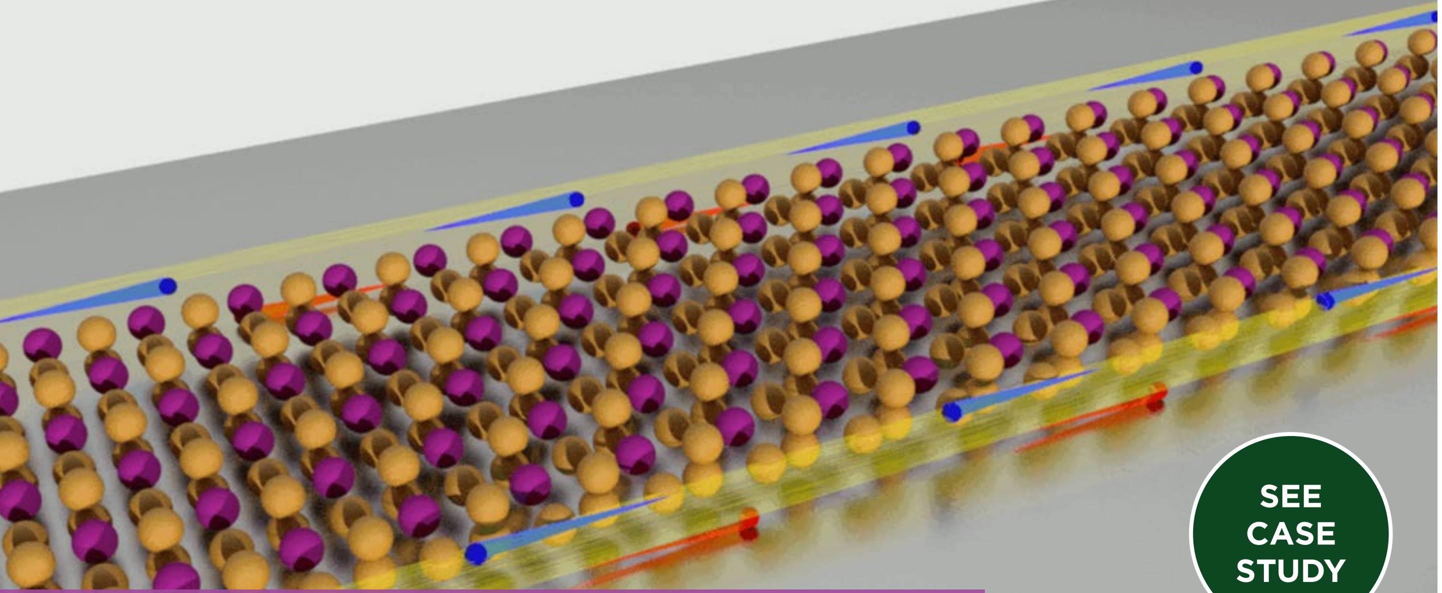
- Tutorials by FLEET partners and advisers on 2D materials, exciton-polaritons and quantum metrics
- An introduction to research translation
- Why sustainable future computing counts: the contribution of AI and data science to society's wellbeing
- Introduction to better modelling of equity initiatives in STEM
- Research updates presented by ECR theme representatives
- Virtual poster sessions each day in iSee, with 10 posters presented each day
- Social activities in iSee: trivia and FLEET quiz
- Mental-health and wellbeing panel
- Plenty of opportunities and spaces for networking and small group discussions.

Online annual workshop in pictures









ENGAGING WITH INDUSTRY

Engaging with industry to establish future partnerships and research translation

> The 2020 edition of the IRDS predicts present and future technological needs, encompassing an immense scope of the electronics, semiconductor and computer industries; everything from applications' needs to device and manufacturing requirements are drilled down in the roadmap.
>
> International Roadmap for Devices and Systems

FLEET is building links with partners interested in novel electronic devices and systems working towards the overarching goal of creating pathways to translations of research outcomes.

Progress towards this important goal in 2020 includes:

- Adding topological transistors to the Institute of Electrical and Electronics Engineers (IEEE) **International Roadmap for Devices and Systems**
- Lodging two provisional patents: topological switching (Fuhrer Monash and Culcer UNSW), and superior thermoelectric materials (X Wang, University of Wollongong)
- Liquid-metals spin-off company initiated with FLEET investigators Prof Kourosh Kalantar-zadeh and Dr Torben Daeneke
- **Seventeen interviews held as part of the Ascend program** with semiconductor/low-energy electronics stakeholders, including industrial physicists and specialists in business development, commercialisation, energy usage in consumer electronics, sensor and piezoelectrics, opto-electronics, semiconductor industry, data centres (energy use, carbon considerations and heat management), nano-electronics, wireless semiconductor chipsets for systems and products, batteries and capacitors, and low-energy IOT
- Talk on future computing for the IEEE chapter in NSW
- Centre seminar by Prof Andrew Dzurak (UNSW) on commercialisation of university research
- Research translation talk at FLEET's annual workshop.

FLEET-wide industry-engagement seminars in 2021 will start in March, kicking off with a talk by technology entrepreneur Dr Erol Harvey (Bionics Institute Australia, miniFAB).

CASE STUDY

PUTTING FLEET SCIENCE ON THE MAP

Engaging with the semiconductor industry and 'beyond CMOS' roadmap

FLEET's quest for topological transistors took a significant step towards wider recognition in the semiconductor industry in 2020 via its first inclusion in the global industry 'roadmap'.

DID YOU KNOW...

The International Roadmap for Devices and Systems is the latest, global, iteration of an industry roadmap that has guided semiconductor development since the 1960s.

For decades, advances in semiconductor technology have been steered by an industry roadmap, the most recent iteration of which is the IEEE International Roadmap for Devices and Systems (IRDS).

This semiconductor roadmap guides development of conventional silicon-based CMOS electronics as well as an array of alternative and complementary future technologies.

For FLEET science to become more visible worldwide, particularly with the international semiconductor industry, it was vital that it be included in the IEEE roadmap. This task was facilitated in 2020 by FLEET Associate Investigator Prof Francesca Iacopi.

FLEET-relevant science is now included in the 'Beyond CMOS' chapter, including:

- Topological-insulator electronic devices (new in 2020)
- Excitonic devices
- Domain wall logic.

The inclusion of FLEET's science in the IRDS will ensure that industrial R&D leaders in semiconductors are aware of our work, and will be able to consider FLEET's breakthroughs among the potential solutions for future low-energy electronics, hence fulfilling the Centre's mission.

The Institute of Electrical and Electronics Engineers (IEEE) is the world's largest professional organisation for the advancement of technology.

Convening an expert panel on the future of electronics

In addition, early in 2020 FLEET and IEEE Australia convened an expert panel for a guided discussion about the future of electronics beyond CMOS and the role semiconductors and other materials can still play through radically novel approaches.

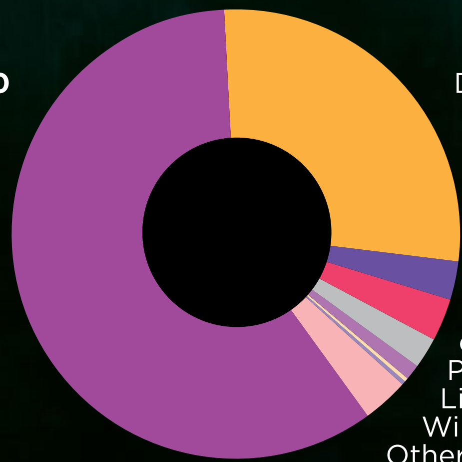
Speakers at the panel included Dr Paolo Gargini (formerly Intel, head of several international semiconductor roadmaps), Prof Michelle Simmons (UNSW; Director, ARC Centre for Quantum Computation and Communication Technology) and FLEET's Prof Michael Fuhrer.

Around 100 attendees dialled in for a webinar and discussions moderated by FLEET Associate Investigator Prof Francesca Iacopi (Chair of the IEEE Electron Devices Society (EDS) Chapter in New South Wales), and Dr David Cortie (Chair, FLEET Communications Committee). This colloquium marked the inauguration of the IEEE NSW Electron Devices Society Chapter.

FLEET ONLINE

FLEET uses the Centre's own online and social media platforms to communicate Centre research results and other news, targetting different audiences via appropriate platforms.

TRAFFIC SOURCE



WEBSITE
FLEET.org.au

Number of **Unique page views** 71,700

Number of **Sessions** 50,700

Number of **New users** 35,400

Number of **Blog posts** 97

Number of **Pages per session** 1.66

TWITTER
@FLEETCentre

Number of **Profile visits** 6172

Number of **Twitter followers** 1138

Number of **Tweet impressions** 549,300

Number of **Members active** 49

607 Number of **Tweets**

Number of **Mentions** 503

LINKEDIN

742 Number of **Followers**

2227 Number of **Page visits**

Number of **Post views** 38,750

FACEBOOK
@FLEETCentre

People reached 28-day avg. 2230

188 Number of **Posts**

Followers FLEET **Facebook page** 644

Number of times **FLEET videos were watched** at 95% 183

Number of people who **Saw our posts** 50,650

Number of people who **Engaged with our posts** 3077

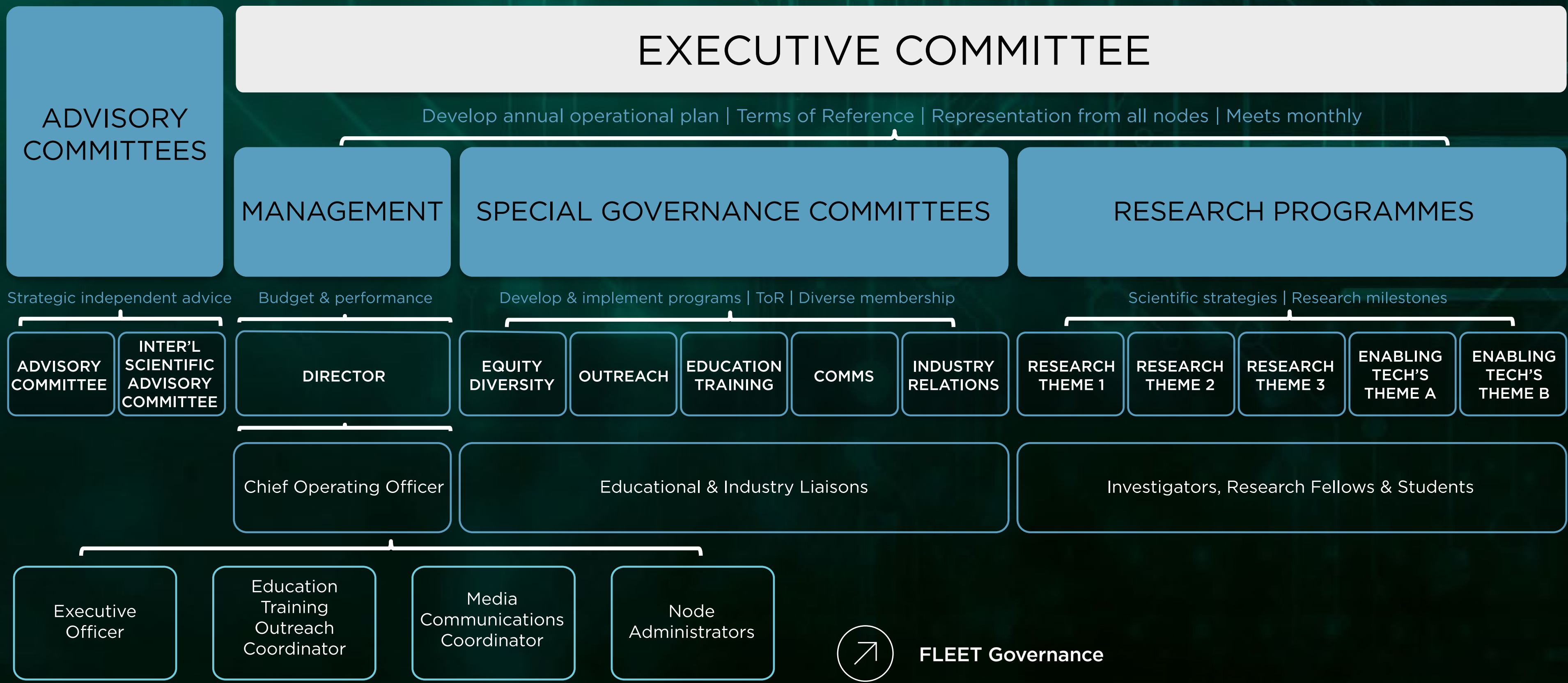
INSIDE FLEET

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

Strategic plan

FLEET Executive team

FLEET Business team



FLEET Governance

ADVISORY COMMITTEE

THE FLEET Advisory Committee commends FLEET for the high value scientific impact the Centre has achieved.

The creativity of FLEET's activities is recognised: Prof Ellen Williams (University of Maryland) referred to the "chaos of creativity," as she was struck by connections between the three very distinct research themes, each with a different time scale.

The Centre's achievements in increasing the number of women in FLEET is recognized, as are FLEET outreach activities to high-school students and a measurable improvement in the participation of members in Centre mentoring programs.

Centre's thoroughness in tracking its KPIs is complimented – Dr An Chen (Semiconductor Research Corporation) noted this is a difficult task for many international research centres.

Finally, the Centre's remarkable commercialisation effort is recognised, with the Liquid-metal spin-off company.

ADVISORY COMMITTEE MEMBERS

Prof Andrew Peele

Director Australian Synchrotron, Australia

Dr An Chen

Executive Director Semiconductor Research Corporation, IBM, USA Nanoelectronics Research Initiative, USA

Dr Cathy Foley

Chief Scientist CSIRO, Australia

Prof Ellen Williams

Distinguished Professor University of Maryland, USA

Prof Luigi Colombo

Fellow Texas Instruments, USA

Prof Joanna Batstone

Director Monash Data Futures Institute

Prof Rebekah Brown

Senior Vice-Provost (Research) Monash University

RECOMMENDATIONS FROM THE AC

- **Tell the story.**
Regarding the priority of raising STEM literacy, it is important to make the connection between Centre's research and real-world applications. FLEET needs to be able to tell the story, with evidence, to show the value of investment in FLEET research.
- **Reach the kids early.**
The identification of gender roles and interest in STEM starts very early, and FLEET should look at outreach activities for kindergarten and primary school children.
- **Evaluate risks.**
A risk-assessment plan based on various scenarios during the next Covid-normal phase is recommended, such as hibernating the program, re-focusing research areas, standing down or re-prioritising existing staff.
- **Monitor impact.**
Laying out the theory of change around each impact to help define, monitor and measure the impact of Centre's activities.
- **Explore investment options.**
Engagement with venture capital firms would assist with finding investment for the new spin-off.
- **Engage with semiconductor industry.**
Work on Centre exposure to Semiconductor Research Corporation type of companies. The nCORE research program at SRC would be a good starting point to establish links with foundries such as Taiwan Semiconductor Manufacturing Company and Samsung.
- **Ensure success.**
In addition to mentoring women in FLEET, the Centre should make sure they have the opportunities to succeed and advance in their careers.
- **Illustrate the 'grand plan'.**
Devising a Gantt chart to illustrate the Centre's story would give a picture of how the Centre evolves over time.
- **Quantify success.**
For the next phase of FLEET, benchmarking the performance of proposed new technologies will be important – how they perform better than existing technologies. It will be important to obtain quantitative measurements. The industry is interested in learning what works, what does not and why.
- **Consider device integration.**
In relations to energy efficiency, FLEET to think about both device and architecture side by side. Expertise from collaborators in areas of computing architecture should be sought.
- **Develop publishing skills.**
Publishing-related workshops such as writing manuscripts and the process around peer-reviews for ECR career development.
- **Evaluate training success.** Determine the value of programs in place by obtaining feedback to find out if the provided training and mentoring has positive impact on outcome.
- **Demonstrating the impact** of the Centre's efforts—in training, outreach, etc—should be the focus moving forward.

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 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.

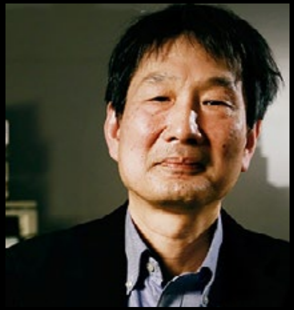
INTERNATIONAL SCIENTIFIC ADVISORY COMMITTEE MEMBERS

Prof Wolfgang Ketterle
Professor of Physics
Massachusetts Institute of Technology, USA

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

FLEET 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 this dissipationless current on and off	Project milestones and research outputs
1.2	Demonstrate exciton superfluidity at elevated temperatures, near room temperature	
1.3	Realise systems that exhibit dissipationless transport when driven out of equilibrium, using periodic (Floquet) and/or strong fields	
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 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	
2.5	Identify opportunities for members to be recognised	Number of awards & grants received by members for 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/industry
3.3	Create a network to commercialise FLEET discoveries	Number of: • relationships with end-users • industry engagement workshops

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

	GOAL	MEASURE
4.	**FOSTER EQUITY / DIVERSITY IN STEM**	
4.1	Foster a culture of equity and inclusiveness	Increased 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 Pathways established to report unacceptable behaviour
4.2	Increase diversity among all cohorts of researchers	Increased number of female researchers/HDR students across FLEET Level of compliance of FLEET HR policy in all Centre recruitments
4.3	Establish career support initiatives for women in FLEET	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 SCIENCE LITERACY**	
5.1	Promote a sustained understanding of FLEET's work	Increased FLEET involvement in the education curriculum & scientific engagement events
5.2	Develop the scientific literacy of Australians through the use of teaching aids, classroom lessons and science demonstrations	Increased number of online and in-person activities developed Increased number of FLEET members participating in STEM Professionals in Schools
5.3	Promote the uptake of STEM subjects in schools	Number of: • activities held in girls schools • students choosing STEM subjects in senior years at partner schools
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 including the ARC, govt., participating nodes and collaborators through research stories, stakeholders' newsletters and social media	Number of: • briefings to government agencies and NGOs • public presentations annually
6.5	Empower FLEET members to communicate their own scientific work by providing communication skills training, resources and incentives	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 competition, and similar
6.6	Push the boundaries of what we're doing in communications, seeking and championing communications "best practice"	• Number of new initiatives each year

EXECUTIVE COMMITTEE

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

The Committee's responsibilities include:

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

FLEET's Executive team comprises leaders of research themes and nodes, and committee chairs.

Michael Fuhrer – Director

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

Michael directs implementation of FLEET's vision and mission and coordinates the three Research themes and two Enabling technologies. With FLEET's Executive team, Michael implements the Centre's strategic plan, directing research, technology transfer, training and mentorship, and outreach.

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

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

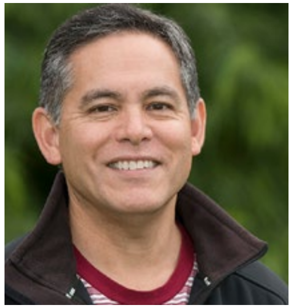
Tich-Lam manages FLEET's operations and its business team. She is responsible for the Centre's financial and operational effectiveness and overseeing activities contributing to the development and delivery of its strategic goals.

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

Executive committee

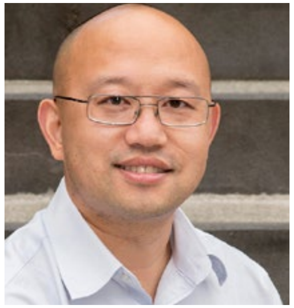
Alex Hamilton
Deputy Director, Leader, Research theme 1
UNSW

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



Kris Helmerson
Leader, Research theme 3
Monash

Xiaolin Wang
Leader, Enabling technology A
UOW



Lan Wang
Leader, Enabling technology B
RMIT

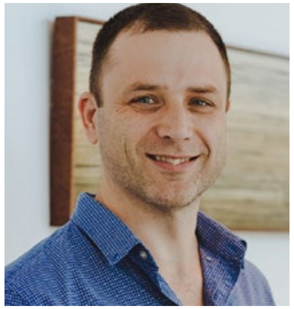
Jeff Davis
Chair, Special Governance Committee – Equity and Diversity
Swinburne

Jared Cole
Chair, Special Governance Committee – Education and Training
RMIT

Julie Karel
Chair, Special Governance Committee – Outreach
Monash

David Cortie
Chair, Special Governance Committee – Communications
UOW

Torben Daeneke
Chair, Special Governance Committee – Industry Relations
RMIT



Matthew Davis
Deputy Chair, Education and Training Committee
UQ

BUSINESS TEAM

> **FLEET's leaders demonstrate by example, and show strong commitment to values.**
>
> 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.

Charlotte Hurry

Executive Officer

Charlotte 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.

Dianne Ruka

Senior Education and Training Coordinator

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

Jason Major

Senior Education and Training Coordinator

Replacing Dianne from December

Kathleen Hicks

Node Administrator, ANU

Kathy supports FLEET operations at ANU and supports node leader Prof Elena Ostrovskaya.

BUSINESS TEAM

Tatiana Tchernova

Node Administrator, Swinburne

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

Cecilia Bloise

Node Administrator, UNSW

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

Catherine Taylor

Node Administrator, UNSW

Filling in for Cecilia from December.

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.

Charles Welcome

Node Administrator, RMIT

Filling in for Nicci Coad January – March

Rebecca Kessler

Node Administrator, RMIT

Filling in for Nicci Coad April - September.

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

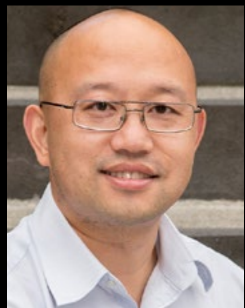
Alexander Nguyen
PhD Student, Monash

Charlotte Hurry
Executive Officer, FLEET

Dimi Culcer
Chief Investigator, UNSW

Elena Ostrovskaya
Committee Deputy Chair, ANU

Kris Helmerson
Chief Investigator, Monash



Lan Wang
Chief Investigator, RMIT

Matthew Davis
Chief Investigator, UQ

Meera Parish
Chief Investigator, Monash

Sumeet Walia
Scientific Associate Investigator, RMIT

Xiaolin Wang
Chief Investigator, UOW

BUILDING FUTURE 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**.

> **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.**
>
> Prof Jared Cole, Chair, Education and Training Committee

EDUCATION AND TRAINING COMMITTEE MEMBERS

Jared Cole
Committee Chair, RMIT

Dianne Ruka
Education and Outreach Coordinator (outgoing), FLEET

Jan Seidel
Chief Investigator, UNSW

Jason Major
Education and Outreach Coordinator (incoming), FLEET

Jeff Davis
Chief Investigator, Swinburne

Jesper Levinsen
Associate Investigator, Monash

Matthew Davis
Committee Deputy Chair, Chief Investigator, UQ

Oleh Klochan
Chief Investigator, UNSW

Peggy Qi Zhang
Research Fellow, UNSW

SPREADING A PASSION FOR SCIENCE: OUTREACH COMMITTEE

FLEET will increase science literacy in the Australian community 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 (from September), Monash

Chris Vale
Chief Investigator, Swinburne

Dianne Ruka
Education and Outreach Coordinator (outgoing), FLEET

Dimi Culcer
Chief Investigator, UNSW

Eliezer Estrecho
Research Fellow, ANU

Errol Hunt
Senior Communications Coordinator, FLEET

Jason Major
Education and Outreach Coordinator (incoming), FLEET

Karina Hudson
Research Associate Investigator, UNSW

Matthew Davis
Chief Investigator, UQ

Nikhil Medhekar
Committee Deputy Chair and Chief Investigator, Monash

Wafa Afzal
PhD Student, UOW

Meera Parish
Committee Chair (January-August), Monash

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
- 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 **Engage with FLEET section.**

> **The Industry Relations Committee leads engagement with industrial partners and establishes groundwork for ultimate translation and commercialisation of FLEET's science into affiliated industries.**
>
> Prof Kourosh Kalantar-zadeh

INDUSTRY RELATIONS COMMITTEE MEMBERS

Torben Daeneke
Committee Chair, RMIT

Errol Hunt
Senior Communications Coordinator, FLEET

Jian-Zhen Ou
Scientific Associate Investigator, RMIT

Kourosh Kalantar-Zadeh
Chief Investigator, UNSW

Matthew Gebert
PhD Student, Monash

Mitchell Conway
PhD Student, Swinburne

Stuart Earl
Committee Deputy Chair, Research Fellow, Swinburne

Tich-Lam Nguyen
Chief Operating Officer, FLEET

Xiaolin Wang
Chief Investigator, UOW

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.**

> **The communications team do a good job advertising seminars, especially around COVID. In terms of collaboration, the past 12 months have seen the fruits of the collaboration that started in 2017, which is a strength.**
>
> FLEET member survey

COMMUNICATIONS COMMITTEE MEMBERS

David Cortie
Committee Chair, UOW

Cecilia Bloise
Node Coordinator, UNSW

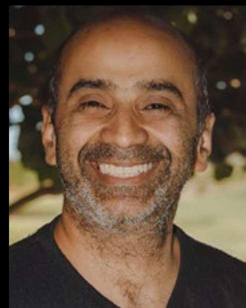
Chutian Wang
PhD Student, Monash

Errol Hunt
Senior Communications Coordinator, FLEET

Jared Cole
Chief Investigator, RMIT

Jeff Davis
Chief Investigator, Swinburne

Matthias Wurdack
PhD Student, ANU



Nagy Valanoor
Committee Deputy Chair, Chief Investigator, UNSW

Stuart Earl
Research Fellow, Swinburne

Vivasha Govinden
PhD Student, UNSW

EDUCATION AND INDUSTRY LIAISONS

FLEET works with specialised educational and outreach liaisons.

EDUCATION AND INDUSTRY LIAISON MEMBERS

Dr Eroia Barone-Nugent
Growing Tall Poppies Science Partnership Program

Dr Toby Bell
Monash University

Camille Thomson
Australian Institute of Policy and Science

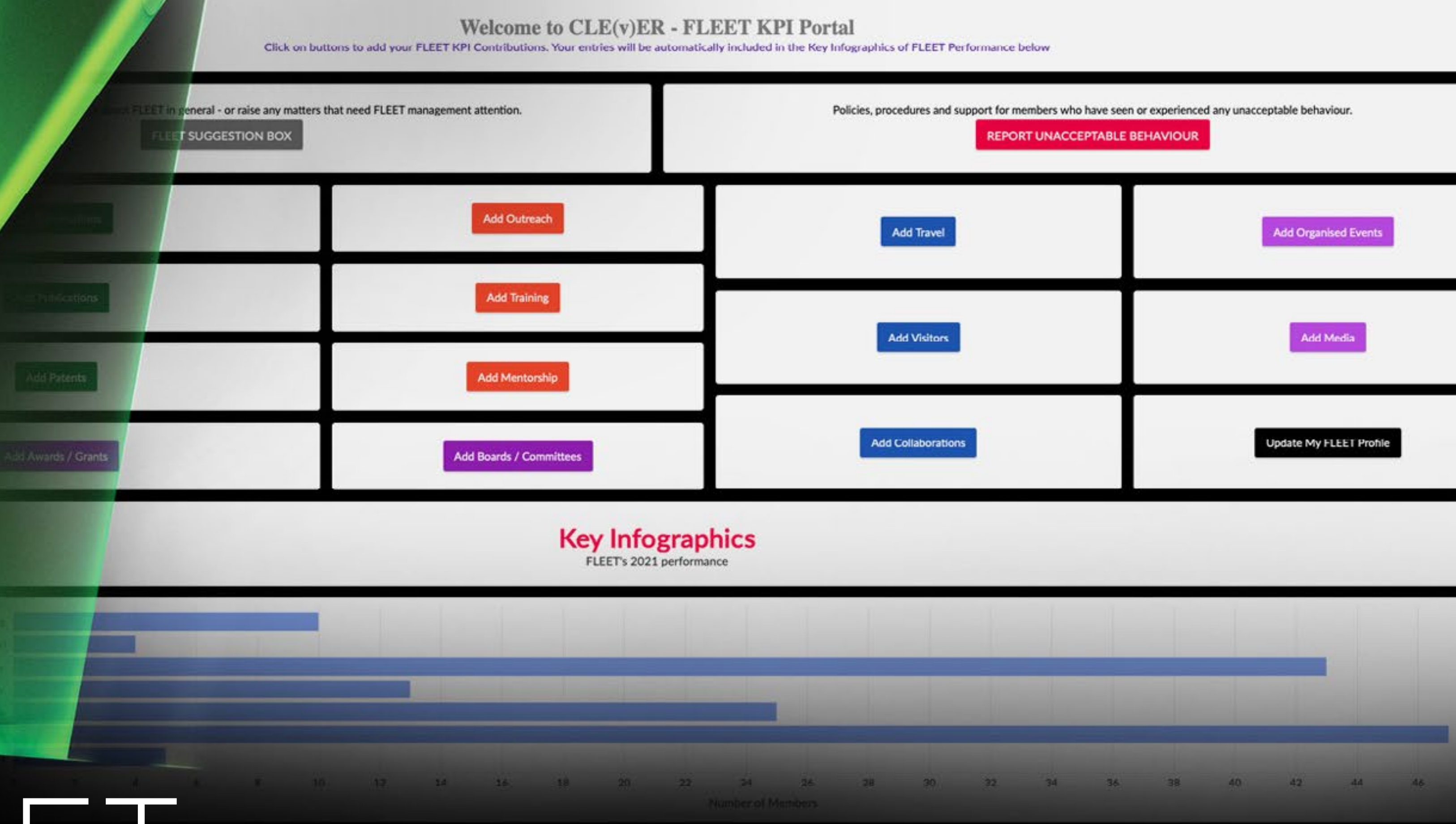
Dr Andrew Hind
General Manager of Molecular Spectroscopy, Agilent Technologies

Mark Muzzin
Entrepreneur

Chris Gilbey
CEO Imagine Intelligent Materials Pty Ltd

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

Dr Steven Duvall
Chief Technology Officer and *General Manager* of Technology Development, Silanna



FLEET PERFORMANCE

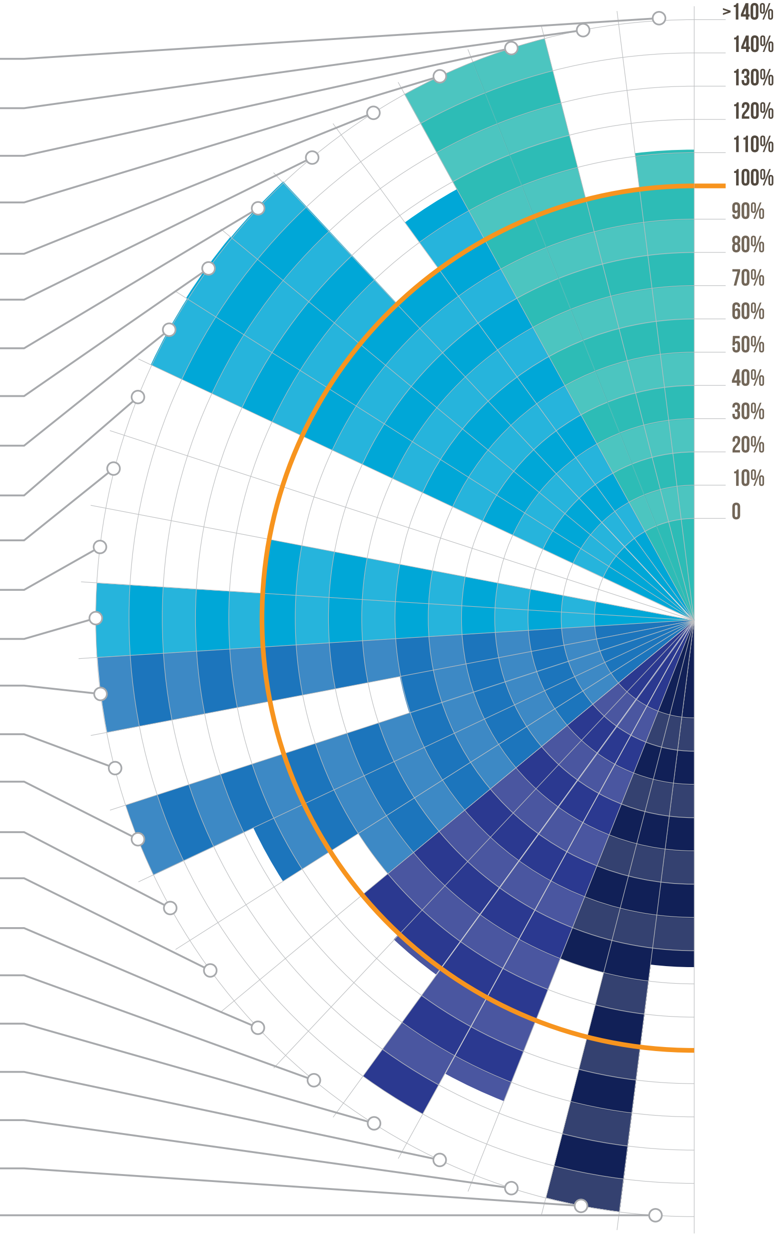
- Key performance indicators
- Publications
- Awards, honours and grants

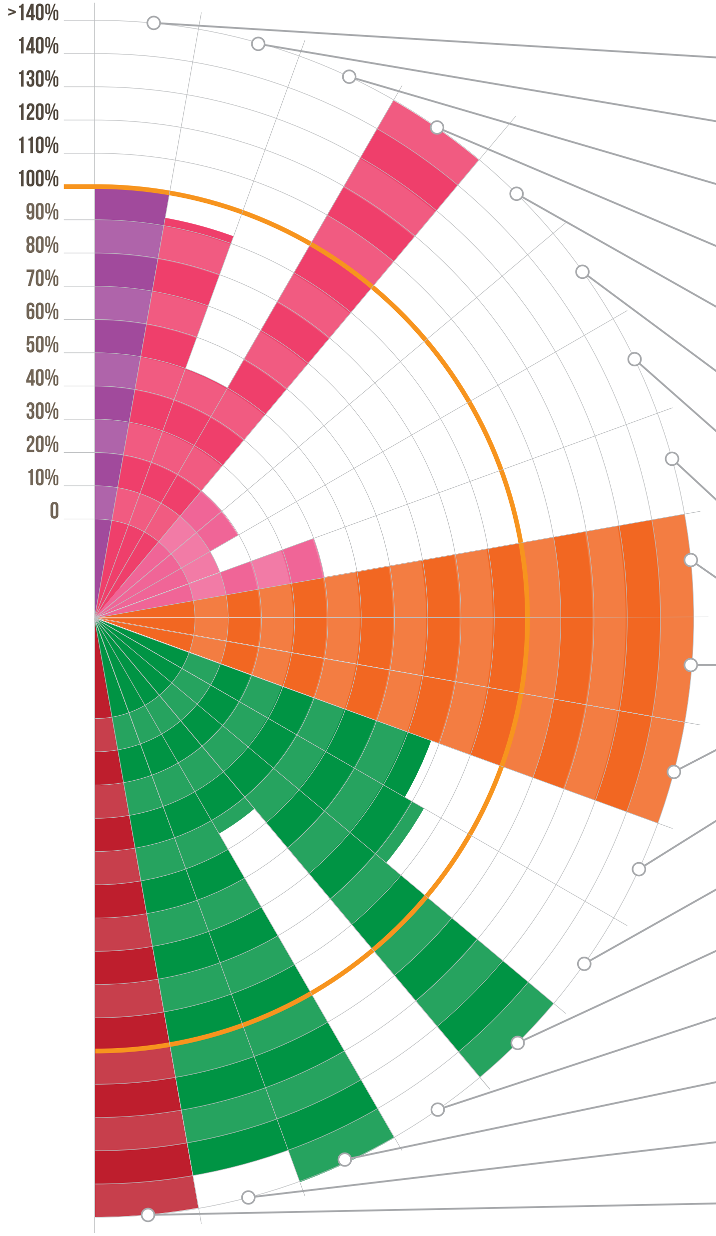
KEY PERFORMANCE INDICATORS

PERFORMANCE MEASURES

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

STANDARD KPI	Target	Actual
Journal articles	100	116
Patents applied	2	2
Technical briefings presented to targeted industry groups	1	6
Publications in journals with IF >7	20	52
Research & professional development courses	6	7
Training workshops on diversity and gender equity	1	1
Centre attendees at training workshops	150	1349
Non-Centre attendees at training workshops	150	512
Workshops held within Australia	2	6
Workshops held outside Australia	2	
National symposium & conferences facilitated	1	
International symposia & conferences facilitated	1	1
Industry engagement workshops to be held	1	3
Postdoctoral researchers (total FTE)	20	39
Honours students (total)	5	3
PhD students (total)	30	59
Associate Investigators (total)	30	35
PhD completions	10	9
Mentoring programs offered by the Centre	4	4
Mentors within the Centre	40	41
Mentors external to the Centre	10	14
FLEET members participated as mentees	55	70
Organisational links in training and mentorship programs	5	4
Presentations to stakeholders	30	61
New organisations collaborating with, or involved in, the Centre	8	6





Actual	Target	CENTRE SPECIFIC KPI
25%	25%	Percentage of women HDRs in FLEET
30%	25%	Percentage of women ECRs in FLEET
20	40	Invited talks at international conferences
3	2	New fellowships awarded to CIs, ECRs and AIs
2	10	International students and ECRs visiting FLEET
6	30	Senior investigators - International visitors FLEET
1	10	Chief investigators visiting partners
6	15	ECR & HDR students visiting partners
18	5	Non-peer reviewed works by FLEET members
534	250	Mentions of FLEET research in the media
2906	600	Unique hits to Centre website, monthly average
942	1200	Hours spent in outreach activities
1710	2000	Primary/secondary students reached in outreach activities
271	75	Primary/secondary teachers reached in outreach activities
2214	5000	Public reached in outreach activities
26	10	Organisational links in education and outreach programs
14	10	End-user relationships established
8766	1500	Other research income secured by Centre staff ('000)

PERFORMANCE MEASURES

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

KPIs IN DETAIL

* *KPI targets unmet due to impact of the global pandemic: conferences, meetings and public events canceled, travel bans, social distancing requirements, lock-downs and laboratory shut-downs and Centre reduced requirement of member outreach hour contributions as a mitigation strategy to look after members' mental health and wellbeing.*

KEY PERFORMANCE INDICATORS	TARGET 2020	ACTUAL 2020
RESEARCH OUTPUTS		
Journal articles	100	116
Patents applied	2	2
Technical briefings presented to targeted industry groups	1	6
Publications in journals with IF >7	20	52
EDUCATION & TRAINING		
Research & professional development courses	6	7
Training workshops on diversity and gender equity	1	1
Centre attendees at training workshops	150	1349
Non-Centre attendees at training workshops	150	512
Workshops held within Australia	2	6
Workshops held outside Australia	2	0*
National symposium & conferences facilitated	1	0*
International symposia & conferences facilitated	1	1
Industry engagement workshops to be held	1	3
FLEET RESEARCH PERSONNEL		
Postdoctoral researchers (total FTE)	20	39
Honours students (total)	5	3
PhD students (total)	30	59
Associate investigators (total)	30	35
PhD completions	10	9*

KEY PERFORMANCE INDICATORS	TARGET 2020	ACTUAL 2020
MENTORING		
Mentoring programs offered by the Centre	4	4
Mentors within the Centre	40	41
Mentors external to the Centre	10	14
FLEET members participated as mentees	55	70
PARTNERSHIP DEVELOPMENT		
Organisational links in training and mentorship programs	5	4
Presentations to stakeholders	30	61
New organisations collaborating with, or involved in, the Centre	8	6
GENDER EQUITY		
Percentage of women HDRs in FLEET	25%	25%
Percentage of women ECRs in FLEET	25%	30%
RECOGNITION		
Invited talks at international conferences*	40	20*
New fellowships awarded to CIs, ECRs and AIs	2	3
PARTNERSHIP DEVELOPMENT		
International students and ECRs visiting FLEET	10	2*
Senior investigators - International visitors to FLEET	30	6*
Chief investigators visiting partners	10	1*
ECRs & HDR students visiting partners	15	6*
FLEET PR & MARKETING		
Non-peer reviewed works written by FLEET members	5	18
Mentions of FLEET research in the media	250	534
Unique hits to Centre website, monthly average	600	2906
OUTREACH		
Hours spent in outreach activities	1200	942*
Primary/Secondary students reached in outreach activities	2000	1710*
Primary/Secondary teachers reached in outreach activities	75	271
Public reached in outreach activities	5000	2214*
Organisational links in education and outreach programs	10	26
End-user relationships established	10	14
NEW FUNDING		
Other research income secured by Centre staff (thousands)	1500	8766

RESEARCH OUTPUTS

PEER-REVIEWED PUBLICATIONS

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DOI **Article Digital object identifier**

***** **publications involving associate investigators**

**publications involving partner investigators**

Impact factor at time of publication

AWARDS HONOURS AND GRANTS

MEMBERS INVOLVED	NAME OF AWARD GRANT SCHEME	GRANT ID	VALUE (AUD)	FUNDING SOURCE
Qi-Kun Xue	2020 Fritz London Prize			Other external funding
Matthias Wurdack	AIP NSW Postgraduate Award		500	Other external funding
Michael Fuhrer, Mark Edmonds, Shaffique Adam	ARC Discovery Project	DP200101345	715,000	Other ARC grants
Matthew Davis	ARC Discovery Project	DP200102239	480,000	Other ARC grants
Meera Parish	ARC Future Fellowship	FT200100619	1,001,328	Other ARC grants
Sumeet Walia, Yuerui (Larry) Lu	ARC LIEF	LE200100032	600,000	Other ARC grants
Jeffrey Davis, Torben Daeneke	ARC LIEF	LE200100051	755,000	Other ARC grants
Lan Wang, Sumeet Walia	ARC LIEF	LE200100071	535,000	Other ARC grants
Joanne Etheridge	ARC LIEF	LE200100132	1,486,000	Other ARC grants
Agustin Schiffrin	ARC LIEF	LE200100151	744,000	Other ARC grants
Julie Karel	ARC LIEF	LE200100174	425,000	Other ARC grants
Alexander Hamilton, Jan Seidel, Michael Fuhrer, Nagarajan Valanoor, Oleh Klochan, Xiaolin Wang, Julie Karel	ARC LIEF	LE200100197	1,102,947	Other ARC grants
Alexander Hamilton, Dimitrie Culcer	ARC Linkage Project	LP200100019	420,696	Other ARC grants
Kristian Helmerson	ARC Linkage Project	LP200100082	451,265	Other ARC grants
Qile Li	Australian Institute of Nuclear Science and Engineering PGRA Scholarship			Other external funding
Cathy Foley	Fellow of the Australian Academy of Science			Other external funding

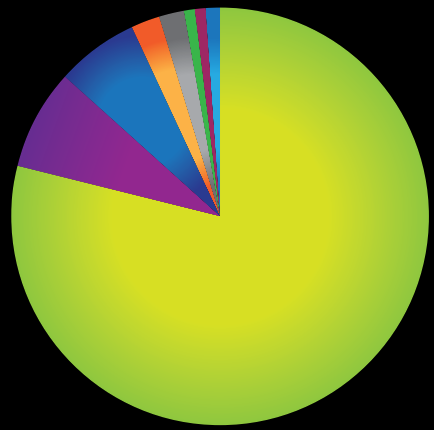
MEMBERS INVOLVED	NAME OF AWARD GRANT SCHEME	GRANT ID	VALUE (AUD)	FUNDING SOURCE
Sumeet Walia	Finalist - Eureka Prize for an Emerging Leader in Science			Other external funding
Kristian Helmerson, Matthew Davis, Matthew Reeves, Shaun Johnstone, Oliver Stockdale	Finalists - Eureka Prize for Scientific Research			Other external funding
Jesse Vaitkus	Ian Snook Physics Prize for highest-achieving PhD student			Other external funding
Agustin Schiffrin	Monash Networks of Excellence Scheme		25,000	Monash University
Tich-Lam Nguyen	Monash School of Physics and Astronomy Travel Award		600	Monash University
Matthew Gebert	Monash Science Award 2020 - Outstanding Contribution by a Graduate Research Student			Monash University
Agustin Schiffrin	Monash Science Strategic Uplift Seed Funding Scheme		20,000	Monash University
Cathy Foley	Queens Birthday Honours			Other external funding
Kourosh Kalantar-zadeh	Robert Boyle Prize for Analytical Science			Other external funding
Peggy Schoenherr, Chi Xuan Trang, Cecilia Bloise, Maria Javaid	Scholarships from Women Leadership Australia: Leading Edge		4,000	Other external funding
Maciej Pieczarka	START scholarship for young Polish Scientists of Foundation for Polish Science			Other external funding
Karina Hudson	Sydney Quantum Academy Postdoctoral Fellowship			Other external funding
Allan MacDonald	Wolf Prize in Physics			Other external funding

CENTRE FINANCE

2020 INCOME SOURCES, EXPENDITURE CATAGORIES AND CARRY FORWARD

REPORTING PERIOD	2020	2021
CARRY FORWARD FROM 2019	**4,756,214**	
INCOME	**Actual ($)**	**Forecast ($)**
ARC (includes indexation)	5,076,300	4,750,000
Monash University	495,999	496,000
University of New South Wales	404,667	404,667
RMIT University	154,571	154,667
Swinburne University of Technology	116,000	116,000
Australian National University	58,000	58,000
University of Queensland	58,000	58,000
University of Wollongong	58,000	58,000
TOTAL INCOME	**6,421,537**	**6,095,334**
EXPENDITURE	**Actual ($)**	**Commitment ($)**
Personnel		5,300,000
– Salaries	4,774,648	
– PhD scholarships	526,061	
Equipment	298,170	117,474
Maintenance & consumables	388,375	382,476
Travel and visitor support	174,980	334,831
Other		
– Workshops and conferences	(6,874)	200,000
– Management and administration	72,433	60.000
– Education, outreach and communications	53,061	145,000
– Centre strategic investment	409,323	
TOTAL EXPENDITURE	**6,690,178**	**6,919,781**
CARRY FORWARD TO 2021	**4,487,573**	

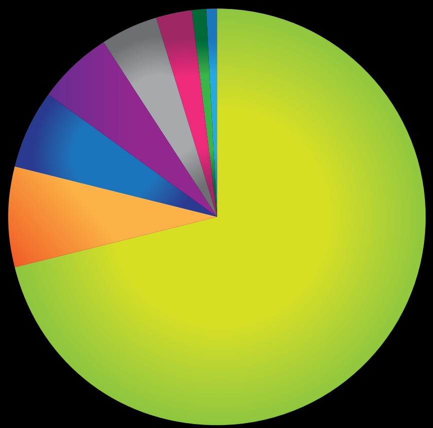
2020 ACTUAL INCOME



- ARC* $5,076,300
- MONASH UNIVERSITY $495,999
- UNIVERSITY OF NEW SOUTH WALES $404,667
- RMIT UNIVERSITY $154,571
- SWINBURNE UNIVERSITY OF TECHNOLOGY $116,000
- AUSTRALIAN NATIONAL UNIVERSITY $58,000
- UNIVERSITY OF QUEENSLAND $58,000
- UNIVERSITY OF WOLLONGONG $58,000

COLLABORATING ORGANISATIONS IN-KIND CONTRIBUTIONS

2020 ACTUAL EXPENDITURE



- SALARIES $4,774,648
- SCHOLARSHIPS $526,061
- CENTRE STRATEGIC INVESTMENT $409,323
- MAINTENANCE AND CONSUMABLES $388,375
- EQUIPMENT $298,170
- TRAVEL AND VISITOR SUPPORT $174,980
- MAINTENANCE AND ADMINISTRATION $72,433
- EDUCATION, OUTREACH AND COMMUNICATION $53,061

COLLABORATING ORGANISATION	2020 ACTUAL $	2021 COMMITMENT $
CURRENT PERIOD		
Monash University	893,526	730,651
University of New South Wales Sydney	679,059	854,650
RMIT University	422,597	362,326
Swinburne University of Technology	379,780	337,015
Australian National University	162,799	71,483
University of Queensland	59,624	168,940
University of Wollongong	148,225	139,535
Australian Nuclear Science and Technology Organisation	176,000	436,000
Australian Synchrotron	434,238	240,465
Beijing Computational Science and Research Center, China	48,000	63,000
California Institute of Technology, USA	26,800	26,800
China High Magnetic Field Laboratory	16,000	20,000
Columbia University, USA	52,580	*
Johannes Gutenberg-Universitat Mainz, Germany	10,200	30,200
Joint Quantum Insitute, USA	105,160	30,000
MacDiarmid Institute - Victoria University of Wellington, New Zealand	14,000	20,000
Max Planck Institute of Quantum Optics, Germany	17,925	34,425
National University of Singapore, Singapore	61,919	99,000
Tsinghua University, China	65,725	118,500
Universitat Wurzburg, Germany	19,512	19,512
University of Camerino, Italy	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, Poland	26,800	26,800
TOTAL IN-KIND CONRIBUTIONS	**3,926,428**	**3,954,132**

IMAGE CREDITS

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Home	Steve Morton, UNSW
Introduction	Jesse Vaitkus
Vision	Steve Morton
Message from the director	Mark Chew, Steve Morton, Jeremy Platt
Innovate	UNSW
Innovate - key data	Steve Morton
FLEET themes	UNSW
Chief investigators	Dianne Ruka
Topological materials	Iolanda Di Bernado, Steve Morton, Matt Rendell
Exciton superfluids	Steve Morton, Phil Dooley, Matt Rendell
Light-transformed materials	Steve Morton, Matt Rendell
Atomically-thin materials	Iolanda Di Bernado, Jeremy Platt, Matt Rendell, Steve Morton
Nanodevice fabrication	Guolin Zheng, Steve Morton, Matt Rendell, Jeremy Platt
Collaborate	Nuriyah Aloufi
Collaborate - key data	Tich-Lam Nguyen
Research collaborations	Steve Morton, Tich-Lam Nguyen

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Professional collaborations	Nuriyah Aloufi, Jeremy Platt, Steve Morton
Equity	Fung Lay
Equity - key data	Michael Fuhrer
Equity and diversity at FLEET	Tich-Lam Nguyen, Jeremy Platt
Women in FLEET	Steve Morton, Grant Turner
Education	Jeremy Platt
Education - key data	Tich-Lam Nguyen
Building future leaders	Steve Morton
Engage	Emanuel Primary School, NSW
Engage - key data	Cecilia Bloise
Engaging with students	Cecilia Bloise, Steve Morton
Sharing FLEET research	Jeremy Platt
Engaging with industry	Kewl Studio
Tracking unexpectedly-fast conduction electrons	Steve Morton, Iolanda Di Bernado
Encasing fragile 2D semiconductors in ultra-thin glass	Phil Dooley
Ultra-fast probing unlocks quantum coherence	Steve Morton
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Using protons to tune interlayer coupling	Steve Morton, Tich-Lam Nguyen
Spotlighting ARC physics	Jeremy Platt
Maintaining international links in the absence of international travel	Tich-Lam Nguyen, Steve Morton
Listening to, and responding to our people	Leon Walker
Supporting future science leaders	Steve Morton
Skilling up our people: research impact and industry engagement	Tich-Lam Nguyen, Jeremy Platt
Engaging senior school students at JMSS	Errol Hunt
Online annual workshop	Tich-Lam Nguyen, Errol Hunt
Putting FLEET science on the map	UNSW
Remote outreach that's also hands-on	Emanuel Primary School, NSW

FLEET
ARC CENTRE OF EXCELLENCE IN FUTURE LOW-ENERGY ELECTRONICS TECHNOLOGIES

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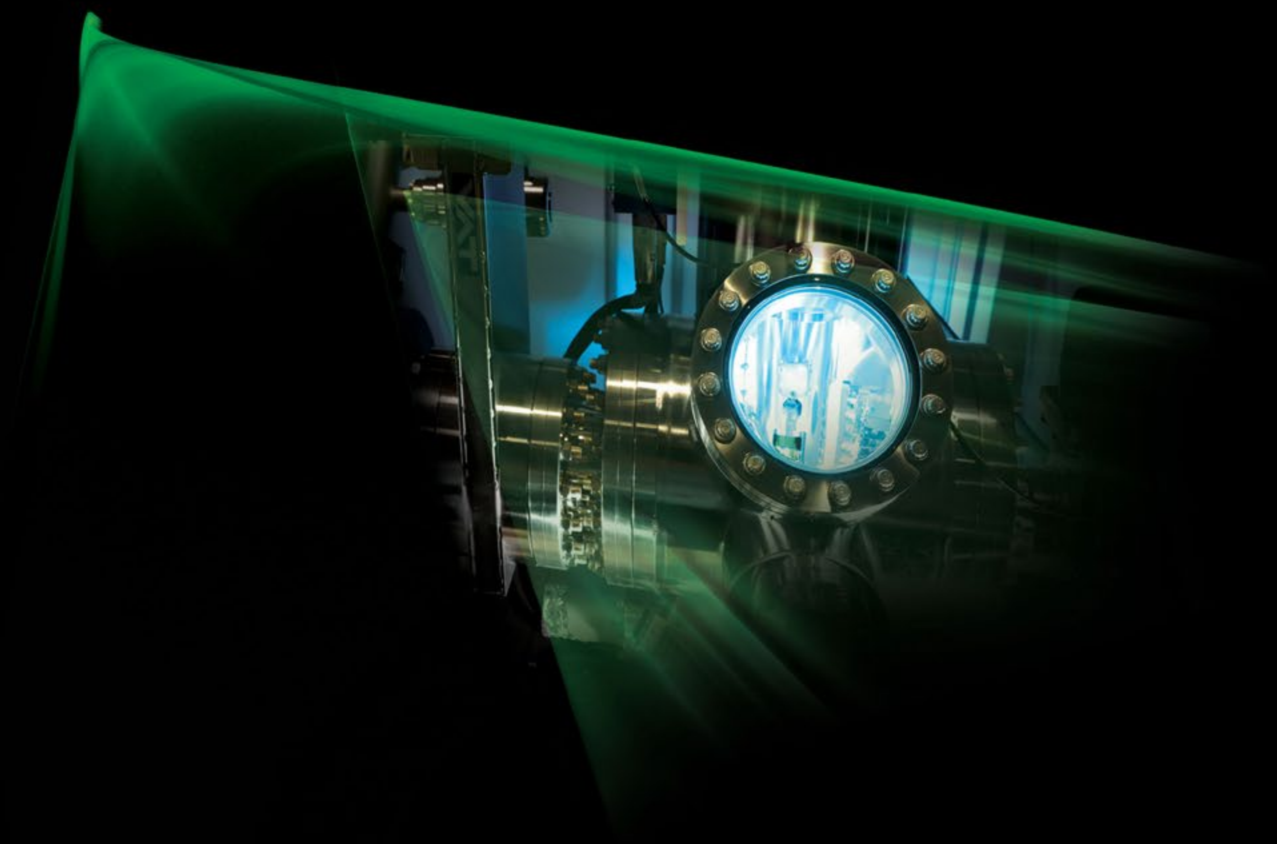
Authorised by FLEET Executive Committee, February 2021
Writing Errol Hunt, FLEET
Editing Margie Beilharz, The Open Desk
Design Idaho Design & Communication

FLEET Online Annual Report https://ar2020.fleet.org.au/



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