
FLEET
2019
ANNUAL REPORT
FLEET
ARC CENTRE OF EXCELLENCE IN
FUTURE LOW-ENERGY
ELECTRONICS TECHNOLOGIES
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ELECTRONICS TECHNOLOGIES

FLEET Scientific Associate Investigator Dr Chi Xuan Trang (Monash)

Image courtesy of Steve Morton

Levitating superconductor

Image courtesy of UNSW

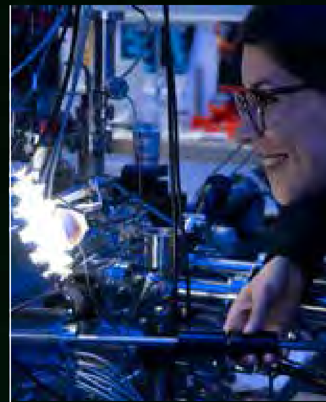
FLEET PhD student Yonatan Ashlea Alava (UNSW)

Image courtesy of Grant Turner

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 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.



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INTRO

FLEET Director Prof Michael Fuhrer is a pioneer of the study of electronic properties of 2D materials, with extensive experience managing large, interdisciplinary research teams.

01

2019 saw high-impact, game-changing scientific results at FLEET, with big collaborative efforts laying the groundwork for even bigger results in the future.

FLEET LAUNCHES
12 JUNE 2018

220
CENTRE MEMBERS AND AFFILIATES

192
INVESTIGATORS AND RESEARCH ASSOCIATES

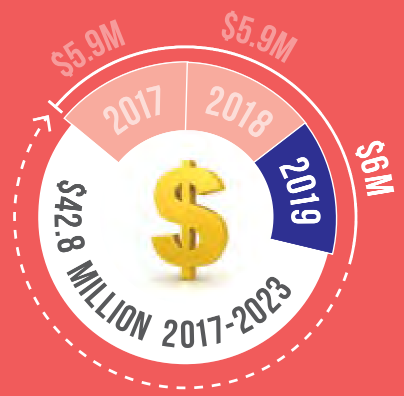
50
EARLY CAREER RESEARCHERS

20
RESEARCH LEADERS FROM 7 UNIVERSITIES

18
INTERNATIONAL PARTNER ORGANISATIONS

2
ADDITIONAL PARTNER ORGANISATIONS IN 2019

2017-2023 RESEARCH FUNDING



$26M IN-KIND COMMITMENT BY COLLABORATING ORGANISATIONS

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.

AND THEN THERE WERE TWO

The silicon chip (CMOS) process has been an extraordinary story of technological innovation.

For more than four decades the semiconductor industry has rapidly and steadily improved CMOS to continuously deliver computer chips with better performance and better energy efficiency at lower cost.

The area occupied by each transistor has halved every two years with such remarkable precision and predictability that the phenomenon is treated as if it was a law of nature, dubbed ‘Moore’s Law’.

But in 2019-20, we are seeing the inevitable signs of the end of Moore’s Law.

In 2015, when FLEET first submitted an expression of interest to the Australian Research Council (ARC) to fund a new centre, four global semiconductor corporations could manufacture transistors with a minimum feature size of 14 nanometres.

Now, five years later, only two companies (Samsung and TSMC) have advanced to 7-nanometre chips. IBM seems stuck at 10 nanometres and Global Foundries announced in late 2018 that it was simply giving up.

Moving beyond 7 nanometres requires a qualitative jump to a new transistor design (a ‘gate-all-around field-effect transistor’ or GAAFET), and the investment required is enormous. The two remaining innovative foundries, Samsung and TSMC, are promising 5-nanometre products in 2020, on schedule, and have plans for 3.5-nanometre devices.

But then what…? The challenges beyond 3.5 nanometres (which should have been only three to four years in the future if Moore’s Law had continued its historical rate) are truly Herculean.

Previously existing economies of scale that supported innovation required to make transistors smaller have largely dried up, and the state-of-the-art technology is now driven by expensive niche applications that require the highest performance and lowest power, largely smartphones.

It now seems very likely that during the course of the FLEET Centre (funded through 2023) we will have witnessed the transition from steady Moore’s Law progress to a virtual standstill, making our Centre’s mission all the more urgent.

BUILDING NETWORKS

2019 marked the second full year of FLEET’s operation.

While 2018 was about building new capacity, 2019 was about building and strengthening collaborative networks.

FLEET’s network is what sets it apart from groups who are just a collection of individual researchers, and in 2019 it was a joy to see our big interdisciplinary teams forming and working together.

As just one example, achieving exciton-polariton condensation in two-dimensional (2D) materials (Research theme 2) has required a team with expertise in 2D materials, optical cavities, device fabrication and optical spectroscopy.

Building networks: Pankaj Bhalla (CSRC) and Dr Hong Liu (Monash University)

A/Prof Qiaoliang Bao’s group at Monash University and Associate Investigator A/Prof Yuerui Lu (ANU) have led the effort to fabricate precision microcavities compatible with 2D semiconductors, while Bao’s group has worked with Women in FLEET Fellow Dr Semonti Bhattacharyya to integrate the 2D semiconductors into the cavities.

They immediately faced an unforeseen challenge: the need for an atomically-thin layer to encapsulate and separate several 2D semiconductor layers while preserving their optical properties.

Materials engineer Associate Investigator Dr Torben Daeneke (RMIT) came to the rescue, with large-area 2D sheets of gallium oxide printed from liquid gallium, in a process developed in FLEET with Prof Kourosh Kalantar-zadeh (UNSW/RMIT).

Dr Jeff Davis (Swinburne) and Prof Elena Ostrovskaya (ANU) were able to measure the optical spectra of gallium oxide-encapsulated 2D semiconductors and demonstrate that the new separating layer works exceptionally well. This gives FLEET an advantage in the race towards exciton-polariton condensation in 2D semiconductors.

Similar stories are playing out across FLEET.

These big, collaborative projects take a lot of time to come to fruition, and right now much of the work is going on behind the scenes. But they are laying the groundwork for high-impact research results to come, only possible in a highly collaborative centre.

CHANGING THE CULTURE

An important aspect of Centres of Excellence is their capacity to change the culture of the way science is done.

FLEET has set out to change the culture by significantly increasing the representation of women in electronic materials research (a field traditionally among the very lowest).

In 2019 FLEET offered prestigious, three-year postdoctoral appointments to the first round of Women in FLEET Fellows. These women-only positions were advertised FLEET-wide and available to a broad range of applicants, who were asked to propose how they might fit into FLEET's program.

Not only did we manage to fill the positions with outstanding young female researchers, we learned something new and surprising: we received a total of 68 applications for the fellowships, while 15 previous, more tightly-targeted, searches had received only 28 women applicants in total.

Our hypothesis is that broad-based searches work better for ensuring that under-represented applicants can find a place in an organisation!

FLEET has disseminated a white paper on the experiences learned from the Women in FLEET program, and we hope the results are taken up by other large science and engineering organisations.

FLEET'S GRAND CHALLENGE: MINIMISING ICT ENERGY TO ENABLE FUTURE COMPUTING

FLEET addresses a grand challenge: reducing the energy used in information and communication technology (ICT), which already accounts for around 8% of the electricity use on Earth and is doubling every 10 years.

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.

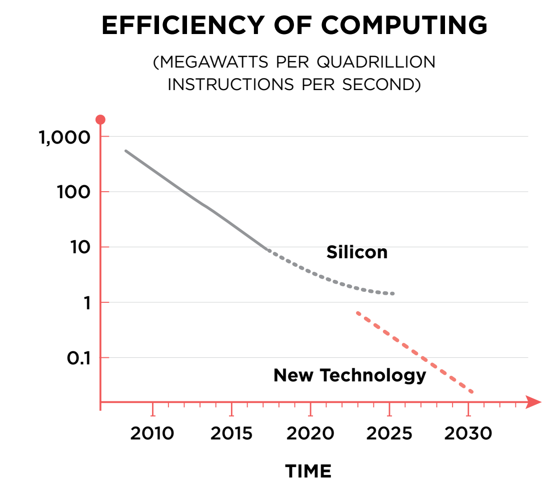
Computers work by activating microscopic switches called transistors – a couple of billion of them are packed into each small computer chip.

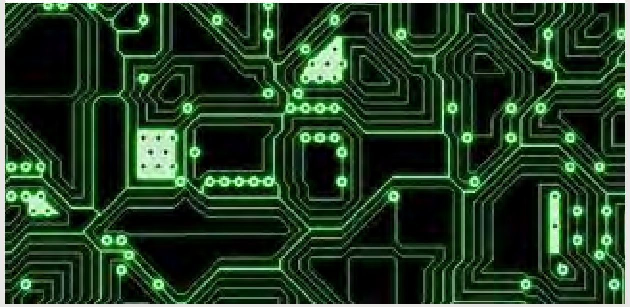
And each time one of those transistors switches, a tiny amount of energy is burnt.

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.





FLEET will develop electronic devices that operate at ultra-low energy, enabling revolutionary new technologies to drive future electronics and computing, while meeting society's demand for reduced energy consumption.

01 JANUARY

Started planning Year 10 elective unit at John Monash Science School

Director Michael Fuhrer met with the Victorian Energy ministry

02 FEBRUARY

Launched FLEET's Carers' grant scheme and Women in FLEET top-up scholarships

Started two collaborative projects with Lockheed Martin

03 MARCH

Launched FLEET-hosted 10th International Conference on Spontaneous Coherence in Excitonic Systems (ICSCE10)

Two new associate investigators: Dmitry Efimkin and Dongchen Qi

04 APRIL

New partner investigator: Kirrily Rule

New associate investigator: Laurent Bellaiche

05 MAY

Launch of Swinburne node BrainSTEM program for young women in science

Top Trumps game developed to celebrate International Year of the Periodic Table

24 members showcased FLEET at Melbourne Knowledge Week

06 JUNE

Deputy Director Alex Hamilton met with the New South Wales Energy ministry

Hosted MP Steve Dimopoulos at Monash node

Co-hosted Idea Factory with the ARC Centre of Excellence for Engineered Quantum Systems (EQUS)

Co-organised first Melbourne Condensed Matter workshop

New associate investigator: Julie Karel

07 JULY

Hosted 30 Indigenous students at Monash winter camp

Hosted MP Paul Scully at Wollongong node

Ran YouRForum 'Got PhD, What Next?' at RMIT

New associate investigator: Francesca Iacopi

08 AUGUST

FLEET's first early-career researchers workshop

Annual strategic workshop

Participated in Sydney Science Fest

New associate investigators: Amgad Rezk and Priyank Kumar

09 SEPTEMBER

New partners: MacDiarmid Institute and High Magnetic Field Labs

New principal investigators: Justin Hodgkiss, Nicola Gaston, Mingliang Tian

Hosted Australian Chief Scientist Alan Finkel at UNSW

10 OCTOBER

Funded strategic seed funding program

Established FLEET-MacDiarmid collaborative research grants

Research theme 2 workshop

Co-hosted an international conference with the International Centre for Theoretical Physics (ICTP)

New associate investigators: Chi Xuan Trang, Sergei Prokhorenko, Yousra Nahas

11 NOVEMBER

Three early-career researchers attended Science Meets Parliament

Research theme 1 workshop

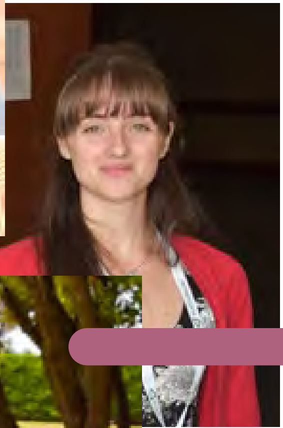
Hosted Gordon Godfrey conference

12 DECEMBER

Annual workshop in Lorne

Held Advisory Committee meeting

New associate investigators: Michelle Spencer, Catherine Stampfl, Susan Coppersmith




HIGHLIGHT ACHIEVEMENTS

FEBRUARY

- A/Prof Meera Parish (Monash) was named an APS 2019 Outstanding Referee by the influential American Physical Society

APRIL

- First Women in FLEET Fellowships offered to Dr Semonti Bhattacharyya (Monash), Dr Iolanda Di Bernardo (Monash) and Dr Peggy Qi Zhang (UNSW)

MAY

- Dr Sam Bladwell (UNSW) made FameLab finals
- Dr Semonti Bhattacharyya (Monash) made FameLab semifinals

JUNE

- Early-career researchers Dr Eliezer Estrecho (ANU), Hareem Khan (RMIT) and Dr Matthew Reeves (UQ) attended the Lindau Nobel Laureate meeting

JULY

- Education and outreach coordinator Dr Dianne Ruka was awarded ‘Exceptional service to the Faculty of Science’ for her outstanding contribution to outreach
- Associate Investigator A/Prof Yuerui Lu (ANU) was named a Heart Foundation Future Leader Fellow and also received the Paul Korner Innovation award

AUGUST

- Fourteen members performed science demonstrations to over 9000 students at Sydney Science Festival
- Two patents lodged for FLEET
- Dr Dimi Culcer (UNSW) was awarded an ARC Future Fellowship

NOVEMBER

- Five Discovery grants – valued at around $2.6 million – awarded to FLEET members
- Seven FLEET women awarded Women and Leadership Australia scholarships

DECEMBER

- Invested $662,000 of strategic funds to support eight projects
- Prof Kourosh Kalantar-zadeh awarded the Walter Burfitt Prize by the Royal Society of NSW for his scientific merits

MESSAGE FROM THE DIRECTOR

2019 was an exciting year for FLEET, with the announcement of some very high-impact, game-changing scientific results bringing international attention to the team.

At the same time, big collaborative efforts within FLEET have really begun to fire on all cylinders in 2019, laying the groundwork for even bigger results in the future.

RESEARCH HIGHLIGHTS

At the beginning of 2019, FLEET's topological materials researchers (Theme 1) reported in Nature the first electric field–controlled switching from topological to conventional insulator in ultrathin Na_3Bi.

In 2019 they demonstrated electrical conduction along the topological edges of ultrathin Na_3Bi over millimetre distances, as well as a unique signature of topological conduction in the magnetic field–dependent resistance of the edges.

FLEET will develop a new generation of ultra-low energy electronics to continue the information revolution, sustainably.

Electronic devices operating at ultra-low energy will enable revolutionary new technologies to drive future electronics and computing, while meeting society's demand for reduced energy consumption.

Theme 1 researchers also made the surprising discovery that few-layer-thick WTe_2 (a topological insulator when thinned to a monolayer) is a ferromagnetic metal, normally a contradiction in terms, but made possible by its two-dimensional (2D) nature (see p26).

FLEET's exciton superfluid (Theme 2) and nano-device fabrication (Enabling technology B) researchers successfully integrated atomically-thin 2D semiconductors into microfabricated photonic cavities, and observed strong coupling of light and excitons (exciton-polaritons) in a 2D semiconductor.

This places FLEET as one of the three groups in the world to achieve this milestone, and a contender in the race to be the first to achieve a superfluid condensate of exciton-polaritons. FLEET researchers also performed decisive experiments to understand the nature of exciton interactions (in a conventional semiconductor); interactions between excitons are critical for them to condense into a superfluid.

Two teams of researchers in FLEET's light-transformed materials theme (Theme 3), in collaboration with the ARC Centre of Excellence for Engineered Quantum Systems (EQUS), reported in back-to-back articles in Science the demonstration of exotic negative temperature states in superfluid condensates of atoms far from equilibrium (see p34). In the solid state, the first experiments within FLEET to manipulate the band structure of a semiconductor with light (the optical Stark effect) were carried out in 2019.

FLEET's atomically-thin materials researchers (Enabling technology A) continue to advance the quality of materials used in FLEET research. In 2019 they demonstrated 3D topological insulators in which the topological surface conduction was dominant to above 50 degrees Kelvin, and advanced the understanding of magnetic dopants in topological insulators (which can produce the resistanceless quantum anomalous Hall effect [QAHE] state) by understanding the effect of iron doping in Sb_2Te_3 (see p42).

They also made the exciting discovery that thinning antimony down to a few atomic layers can stabilise an exotic insulating state called an excitonic insulator, with intriguing connections to exciton superfluids studied in Theme 2.

> FLEET WILL extend the information technology revolution sustainably into the future through new, more energy-efficient computing technology developed here in Australia.
>
> **Prof Michael Fuhrer**
> Director, FLEET

Enabling technology B researchers established critical facilities at Monash University, UNSW and RMIT University for stacking different atomically-thin materials one on another to form new structures, called 'van der Waals heterostructures' after the type of bonding between the atomically-thin layers.

This represents a transfer of knowledge from our partner Columbia University, which pioneered the process. Enabling technology B researchers also demonstrated the fabrication steps necessary to create customised photonic cavities and integrate atomically-thin semiconductors into the cavities for exciton-polariton experiments in Theme 2.

DID YOU KNOW...

Already, ICT is responsible for the same climate-change contribution as the entire aviation industry (2% of total contributions).

NEW PARTNERSHIPS

FLEET continued to expand its partner network in 2019. FLEET announced a partnership with the MacDiarmid Institute, the premier materials science institute in New Zealand, with MacDiarmid co-directors Nicola Gaston and Justin Hodgkiss as FLEET Partner Investigators. FLEET investigators already have a significant track record of collaboration with our neighbours in New Zealand and we look forward to forming new links. FLEET and MacDiarmid Institute have kicked off the new partnership by funding three competitively bid seed grants for new projects with FLEET–MacDiarmid teams, with another round of funding coming in 2020.

FLEET also announced in 2019 a partnership with the High Magnetic Field Laboratory of the Chinese Academy of Sciences, with Vice-Director Mingliang Tian as Partner Investigator. The High Magnetic Field Laboratory is one of the premier laboratories in the world for investigations of materials properties under extreme magnetic fields and temperatures. While FLEET aims to make devices working at room temperature and without any magnetic fields, high magnetic fields are a powerful tool for understanding the electronic properties and behaviour of new materials, and we expect FLEET researchers to benefit from the new partnership.

REMARKABLE OUTREACH

Part of FLEET's mission is to communicate to the public the importance of our work, and of science, technology, engineering and mathematics (STEM) research, in solving society's largest problems.

FLEET set very ambitious goals for outreach and communication at the outset. Still, in 2018 we found that we had smashed our communications goal of 40 media mentions per year, so voluntarily increased the goal to 250. We then managed to best this with over 400 mentions in 2019.

In 2019 we also far exceeded our goals for reaching students and members of the public, reaching over 10,500 students and 11,000 members of the public through programs like our partnership with the Monash Tech School and participation in the Sydney Science Festival.

As a result we will be updating our goals to aim even higher in 2020!

VALE SHAUN JOHNSTONE

This year we lost a brilliant young researcher and member of the FLEET family, Dr Shaun Johnstone.

Shaun was an innovative researcher, a cheerful contributor to FLEET's outreach program, and a warm colleague and friend to many in the Centre, and his loss is tragic. We pay tribute to our friend and colleague on p35.

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

2020 CENTRE PRIORITIES

- Respond to COVID-19 situation:
  - Retain Centre cohesion
  - Adjust to limits on research/ operations
  - Look after our people
- Recruit and retain female early-career researchers – our 2020 target is 25%
- Engage with industry:
  - Change culture to increase members' engagement
  - Identify relevant local end users
  - Find new opportunities for engagement
- Turbo-charge engagement with international scientific advisers
- Prepare for upcoming Centre mid-term review.

INNOVATE

Dr Golrokh Akhgar synthesises topological materials to study their operation in low-energy devices.

02

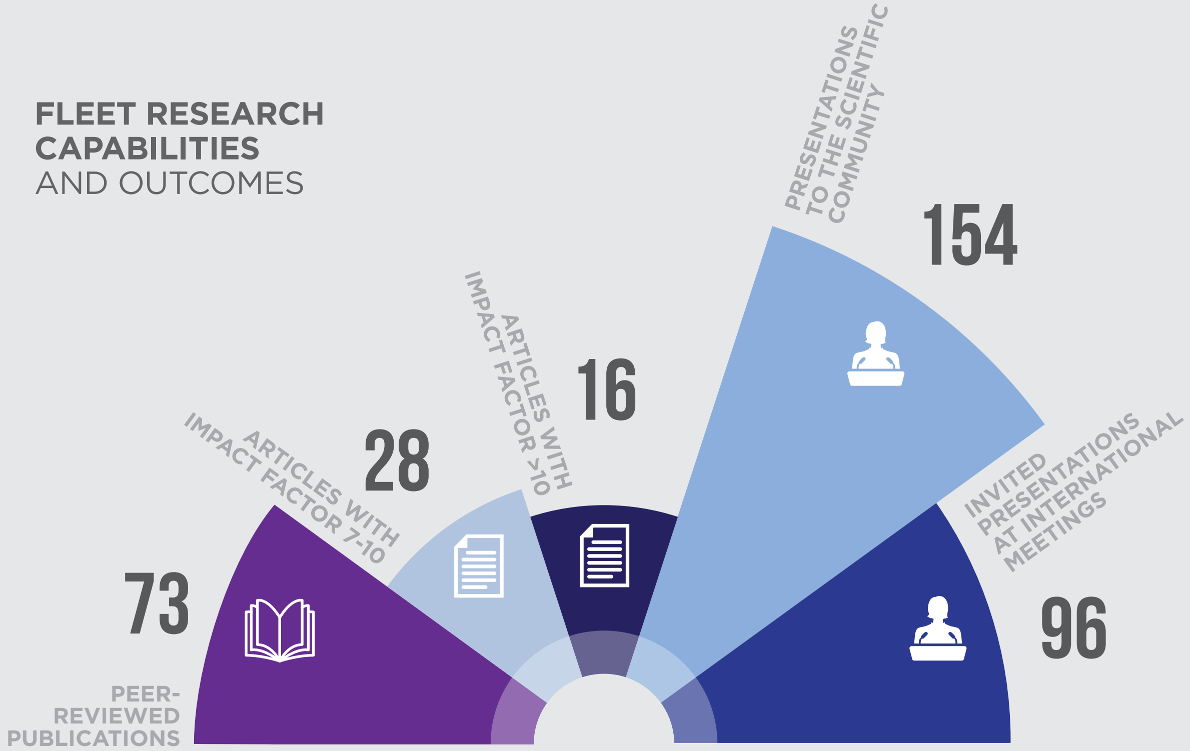
FLEET is pursuing the following research themes to develop systems in which electrical current can flow with near-zero resistance:

- **Topological materials**
- **Exciton superfluids**
- **Light-transformed materials**

The above approaches are enabled by the following technologies:

- **Atomically-thin materials**
- **Nanodevice fabrication**

FLEET RESEARCH CAPABILITIES AND OUTCOMES



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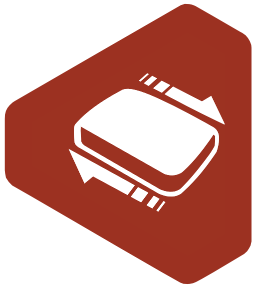


RESEARCH THEME 1: TOPOLOGICAL MATERIALS

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 'back-scattering' that dissipates energy in conventional electronics.

See p24

RESEARCH THEME 2: EXCITON SUPERFLUIDS

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

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

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

See p28

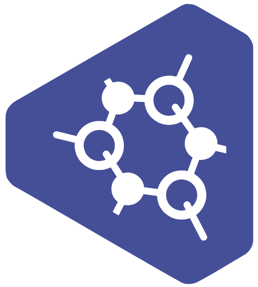
RESEARCH THEME 3: LIGHT-TRANSFORMED MATERIALS

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

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

See p32

These research approaches are enabled by the following technologies:



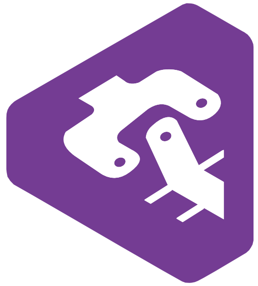
ENABLING TECHNOLOGY A: ATOMICALLY-THIN MATERIALS

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

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

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

See p36



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.

See p40

FLEET CHIEF INVESTIGATORS BY THEME

MICHAEL FUHRER

Director, Node leader, Monash University

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

Deputy Director, Node leader, 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.

ELENA OSTROVSKAYA

Node leader, ANU

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

KRIS HELMERSON

Monash

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.

XIAOLIN WANG

Node leader, UOW

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.

LAN WANG

Node leader, RMIT

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.

CHRIS VALE

Node leader, Swinburne

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

MATTHEW DAVIS

Node leader, UQ

Within Research theme 3, 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.

> I LOVE FLEET's inclusive environment, which stimulates scientific ideas. Collaborations with world-leading experts in their areas leads to cutting-edge fundamental physics, with all of us motivated by a potentially disruptive technological application goal.
>
> **Dr Agustin Schiffrin**
> *FLEET Chief Investigator, Monash*

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.

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.

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.

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.

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.

MEERA PARISH

Monash

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

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.

QIAOLIANG BAO

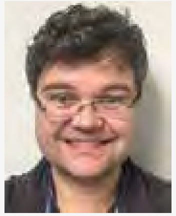
Monash

Qiaoliang investigates waveguide-coupled 2D semiconductors in Research theme 2 and plasmon-coupled 2D materials and devices in Enabling technology B, focusing on effects of light-matter interactions.

PARTNER INVESTIGATORS

Allan MacDonald
University of Texas

Andrea Perali
University of Camerino



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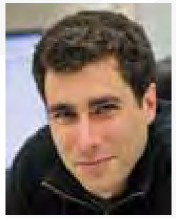

Gil Refael
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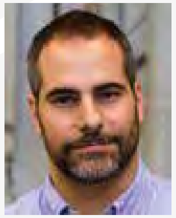
Beijing Computational Science Research Center

Ian Spielman
University of Maryland

Jairo Sinova
Mainz University

James Hone
Columbia University



Johnpierre Paglione
University of Maryland

Justin Hodgkiss
MacDiarmid Insitute

Kirrily Rule
ANSTO

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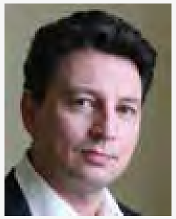

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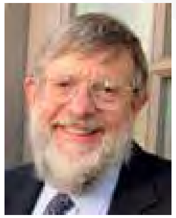

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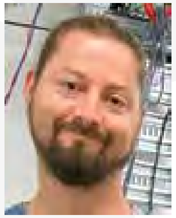

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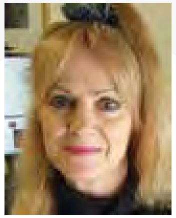

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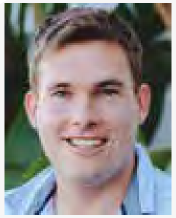

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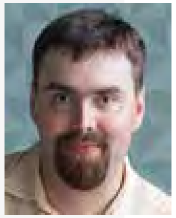

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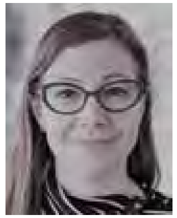

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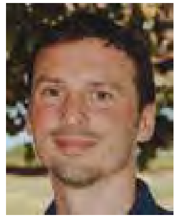

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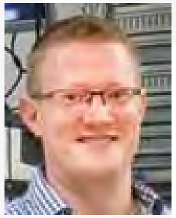

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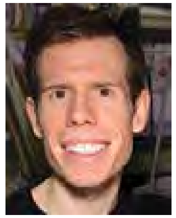

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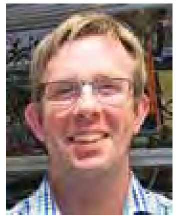

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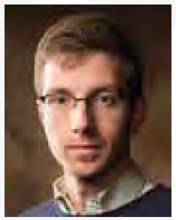

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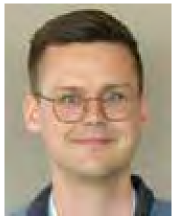

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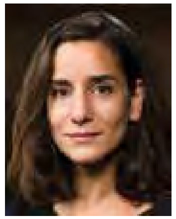

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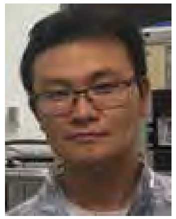

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RESEARCH FELLOWS

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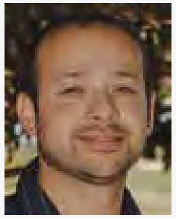

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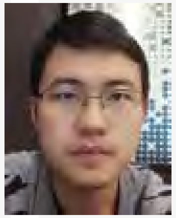

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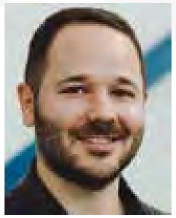

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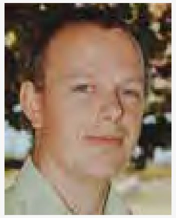

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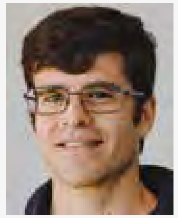

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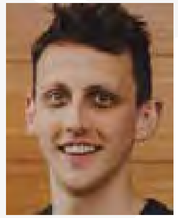

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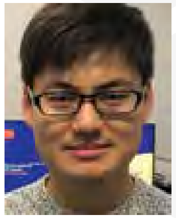

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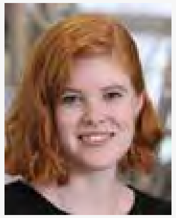

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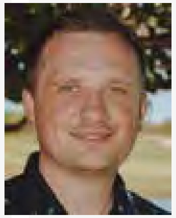

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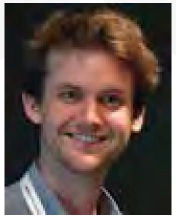

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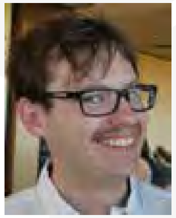

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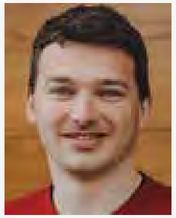

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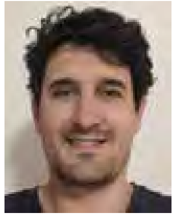

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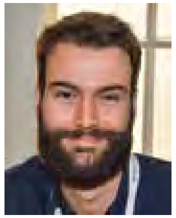

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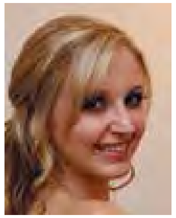

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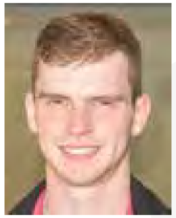
LEGEND

- Research theme 1, topological materials
- Research theme 2, exciton superfluids
- Research theme 3, light-transformed materials
- Enabling technology A, atomically-thin materials
- Enabling technology B, nano-device fabrication

PHD STUDENTS



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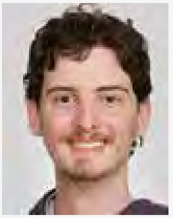

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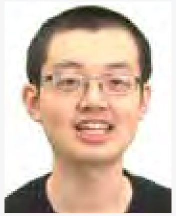

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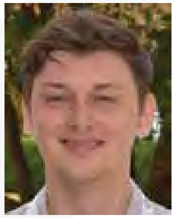

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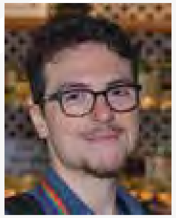

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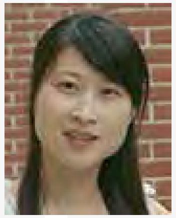

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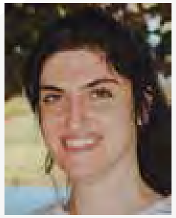

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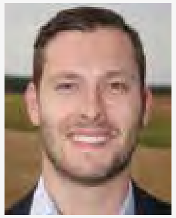

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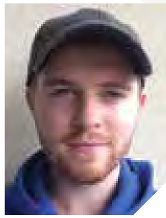

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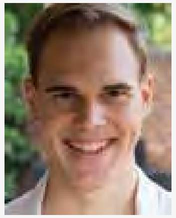
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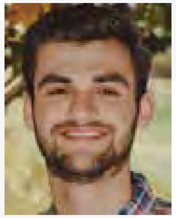
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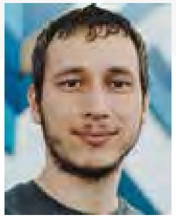
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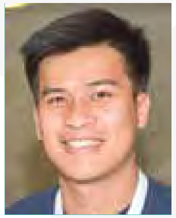
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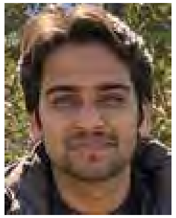
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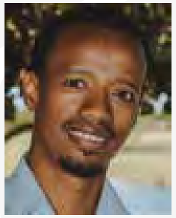
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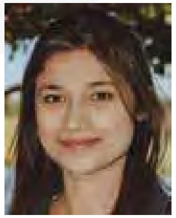
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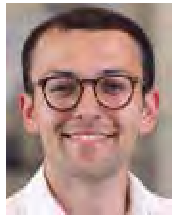
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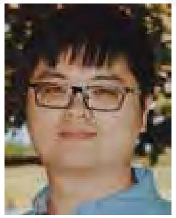
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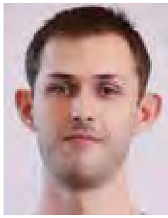
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PROF ALEX HAMILTON

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, and could potentially hail a new era of ultra-low energy electronics."

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

Research outputs: 210+ papers, 3900+ citations, h-index 31 (Scopus)

RESEARCH THEME 1:

TOPOLOGICAL MATERIALS

FLEET's first 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 'back-scattering' of electrons 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.

IN 2020, FLEET WILL:

- Develop techniques for electrical probing of UHV-prepared topological materials
- Understand the phases of 2D bismuth on various substrates
- Optimise a 2D ferromagnetic material with a high phase-change temperature
- Understand topological protection in interacting topological insulators.

2019 HIGHLIGHTS

- Electric-field-tuned transition from trivial to topological insulator in Na_3Bi, and edge-state transport
- Synthesised atomically-thin bismuth
- Numerically simulated effective tight-binding models for few-layer polytypes of bismuth
- Made first observation of a native ferroelectric metal (see p26).

A new low-temperature fridge installed in the FLEET labs at UNSW will allow study of 2D systems in advanced semiconductor devices.

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.

DEFINITIONS

artificial topological systems Artificial analogues of graphene and 2D topological insulators

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

dissipationless current Electric current that flows without wasted dissipation of energy

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

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

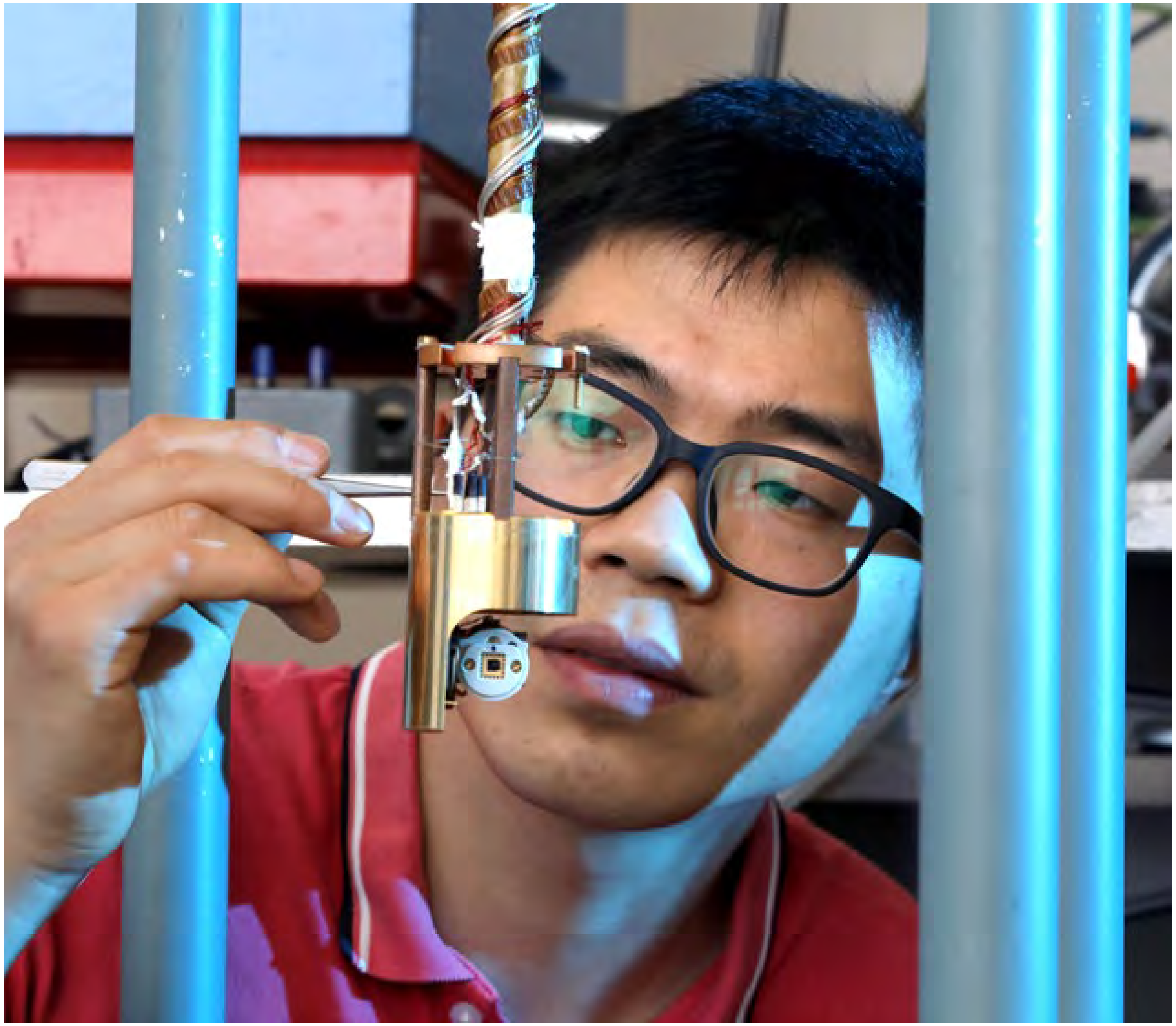
topological materials A relatively new class of material that is electrically insulating in its interior, but conducts along its edges

topological Dirac semimetal (TDS) Topological material at the boundary between conventional insulators (which don't conduct) and topological insulators (which conduct along their edges)

UHV Ultra-high vacuum

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

FLEET Research Fellow Dr Feixiang Xiang fabricated the WTe_2 crystals and studied their electronic structure using transport measurements



CASE STUDY

FIRST OBSERVATION OF A 'NATIVE' FERROELECTRIC

FLEET researchers make first observation of a native ferroelectric metal

The study represents the first example of a native metal with bistable and electrically-switchable spontaneous polarisation states – the hallmarks of ferroelectricity.

Conventionally, ferroelectricity has been observed in materials that are insulating or semiconducting rather than metallic, because conduction electrons in metals screen out the static internal fields arising from the dipole moment. However 2D materials may avoid this paradox by having metallic conduction in the plane of the material, which does not screen an out-of-plane ferroelectric polarisation.

Ferroelectric materials are keenly studied at FLEET for their potential use in low-energy electronics, 'beyond CMOS' technology.

"We found coexistence of native metallicity and ferroelectricity in bulk crystalline tungsten ditelluride (WTe_2) at room temperature," explains study author FLEET Research Fellow Dr Pankaj Sharma.

"We demonstrated that the ferroelectric state is switchable under an external electrical bias and explain the mechanism for 'metallic ferroelectricity' in WTe_2 through a systematic study of the crystal structure, electronic transport measurements and theoretical considerations."

"A van der Waals material that is both metallic and ferroelectric in its bulk crystalline form at room temperature has potential for new nano-electronics applications," says co-author FLEET Research Fellow Dr Feixiang Xiang.

Such materials can be considered similar to magnets, which display permanent magnetism. Ferroelectric materials similarly maintain a permanent electric polarisation, which gives rise to a permanent electric dipole moment.

This spontaneous electric dipole moment can be repeatedly transitioned between two or more equivalent states or directions upon application of an external electric field – a property utilised in numerous ferroelectric technologies, for example, nano-electronic computer memory, medical ultrasound transducers, infrared cameras, submarine sonar, vibration and pressure sensors, and precision actuators.

The switchable electric dipole moment of ferroelectric materials could, for example, be used as a gate for the underlying 2D electron system in an artificial topological insulator.

In comparison with conventional semiconductors, the very close (sub-nanometre) proximity of a ferroelectric's electron dipole moment to the electron gas in the atomic crystal ensures more-effective switching, overcoming limitations of conventional semiconductors where the conducting channel is buried tens of nanometres below the surface.

Devices containing high-grade WTe_2 crystals were built and studied at FLEET's UNSW node, in part using facilities of the NSW node of the Australian National Fabrication Facility.

This research relates to FLEET milestones 1.2 and 1.4 (see p84).

The study was published in *Science Advances* in July 2019, vol. 5, iss. 7 (see publication 53, p98).

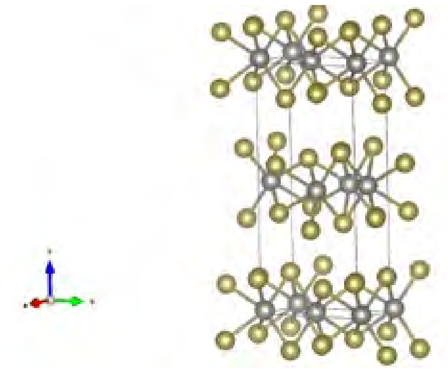
More at FLEET.org.au/ferroelectric

> DISCOVERING THIS coexistence of metallicity and ferroelectricity was one of my highlights from the Centre in 2019. It was a slightly non-intuitive result that a metal could coexist with a permanent polarisation.
>
> **Dr Julie Karel**
> *FLEET Scientific Associate Investigator, Monash University*

COLLABORATING FLEET PERSONNEL:

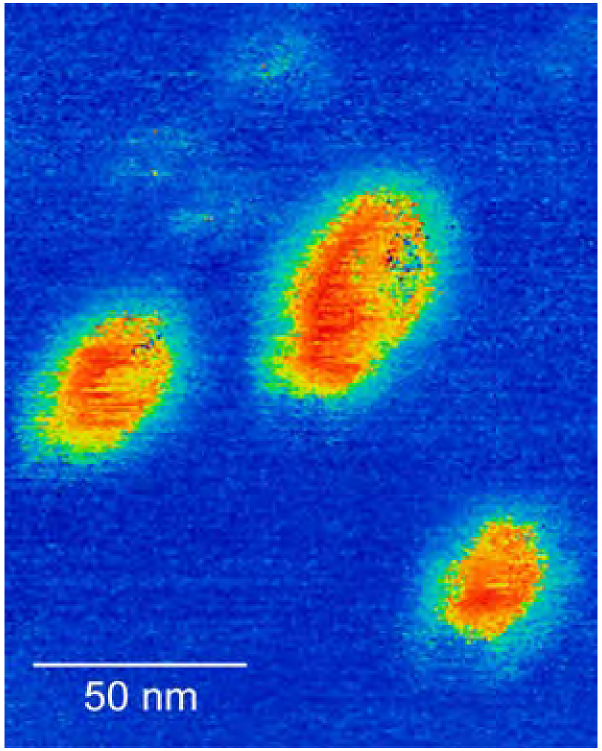
- Research Fellow Pankaj Sharma (UNSW)
- Research Fellow Feixiang Xiang (UNSW)
- Chief Investigator Alex Hamilton (UNSW)
- Chief Investigator Jan Seidel (UNSW)

FLEET Research Fellow Dr Pankaj Sharma (UNSW)



***Above:** Tungsten ditelluride WTe_2 crystals in a layered, orthorhombic structure*

***Below:** Ferroelectric domains in WTe_2 crystal (PFM imaging)*



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

RESEARCH THEME 2:

EXCITON SUPERFLUIDS

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

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

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

Researchers are seeking to create superfluid flows using three approaches:

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

If exciton-superfluid devices are to be a viable, low-energy alternative to conventional electronic devices, they must be able to operate at room temperature, without energy-intensive cooling.

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

A/Prof Meera Parish (Monash)

IN 2020, FLEET WILL:

- Investigate routes to condensation of exciton-polaritons in TMD monolayers
- Characterise carrier dynamics and low-energy interactions in excitonic systems
- Investigate transition to Bardeen-Cooper-Schrieffer (BCS) regime
- Theoretically demonstrate emergent flow states of superfluids between reservoirs.

2019 HIGHLIGHTS

- Investigated interaction of polaritons in an inorganic semiconductor at low temperature (4 degrees Kelvin).
- Established fabrication facilities and techniques to produce microcavities containing 2D monolayer semiconductors
- Observed exciton-polaritons in cavity containing 2D monolayer semiconductors
- Observed elusive excitonic insulator phase (see p30).

DEFINITIONS

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

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

Bose-Einstein condensate (BEC) A quantum state occurring at ultra-cold temperatures

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

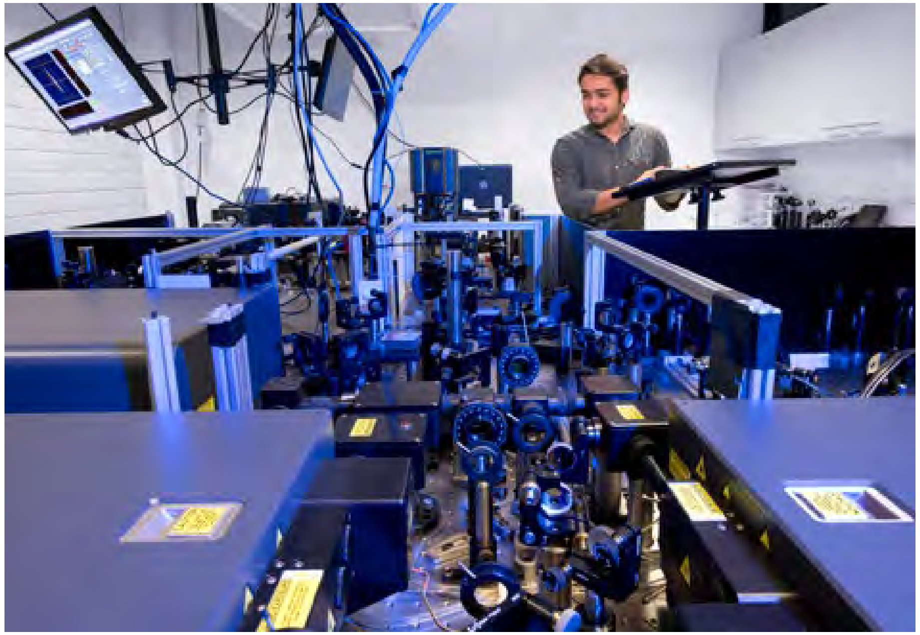
microcavities A micrometre-scale structure; an optical medium sandwiched between ultra-reflective mirrors, used to confine light such that it forms exciton-polaritons

monolayer A single 2D layer of material

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

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

Clockwise from left: Meera Parish (Monash), Jesper Levinsen (Monash), Matt O'Brien (UNSW), Oleg Sushkov (UNSW), Elena Ostrovskaya (ANU), Maciej Pieczarka (ANU)

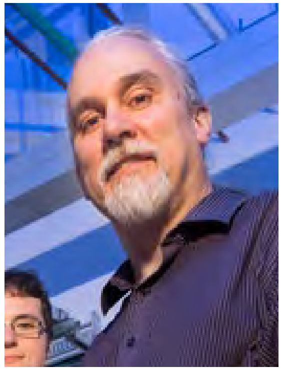


PhD student Rishabh Mishra in ultrafast spectroscopy lab, used in themes 2 and 3

CASE STUDY

NEW CLASS OF MATERIALS FOUND: EXCITONIC INSULATOR

Prof Xiaolin Wang (UOW)



Prof Michael Fuhrer (Monash)

COLLABORATING FLEET PERSONNEL:

- Associate Investigator Zhi Li (UOW)
- Research Fellow Zengji Yue (UOW)
- Associate Investigator David Cortie (UOW)
- Chief Investigator Michael Fuhrer (Monash)
- Chief Investigator Xiaolin Wang (UOW)

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.

First observation of excitonic insulator; a new, exotic state first predicted in 1960s

The discovery of new phases of matter is one of the major goals of condensed-matter physics and key for FLEET's mission to develop new technologies for low-energy electronics.

A FLEET University of Wollongong (UOW) – Monash University collaboration this year found evidence of a new phase of matter predicted in the 1960s by many pioneers in condensed-matter physics: the excitonic insulator.

The unique signatures of an excitonic insulating phase were observed in antimony Sb(110) nanoflakes.

Excitonic insulators are potentially capable of carrying exciton superfluids, in which electrical current can flow with minimal wasted dissipation of energy.

"In the 1960s, it was proposed that in small indirect bandgap materials, excitons can spontaneously form because the density of carriers is too low to screen the attractive interaction between electrons and holes," said lead author FLEET Associate Investigator Dr Zhi Li.

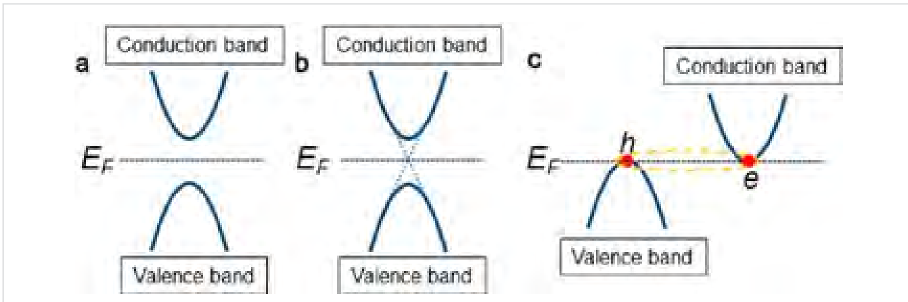
The result is a novel strongly-interacting insulating phase known as an excitonic insulator, which occupies the critical transition point between insulator and metal.

In an excitonic insulator, bosonic particles rather than electrons determine the physical properties.

Excitonic insulators have been predicted to host many novel properties, including crystallised excitonium, superfluidity and excitonic high-temperature superconductivity.

Breakthroughs in finding this new class of insulators have attracted keen attention among condensed-matter physicists and 2D-material scientists.

Excitons, which are strongly-bound pairs of electrons and holes, are formed through the attractive electron-hole (Coulomb) interaction.



Electronic band diagrams for three types of insulators: (a) conventional insulators with bandgap between valence and conduction bands, (b) topological insulators, (c) excitonic insulators

> SOLVING PUZZLES from experiments is at the heart of physics. Every five years something completely new and fascinating is observed in experiments, opening new fields of study.
>
> **Dr Dmitry Efimkin**
> *FLEET Scientific Associate Investigator, Monash University*

If such excitons could form spontaneously, the result would be an excitonic insulator phase.

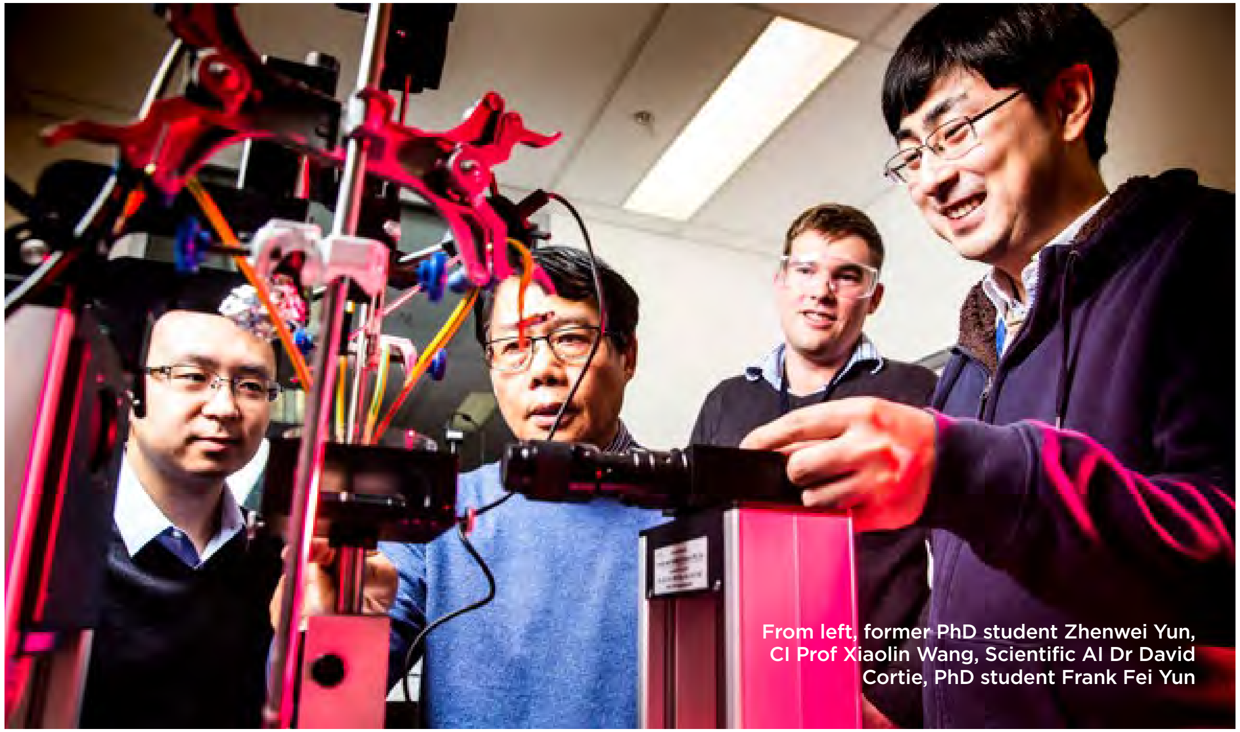
No previous material studies have had sufficient attractive binding energy between electrons and holes to overcome the large bandgap energy of semiconductors and insulators, and thus create electron-hole pairs.

In this work, the researchers took advantage of the strong Coulomb interaction in 2D materials (in this case, antimony of few-atom thickness) to promote the excitonic insulator phase.

The findings also provide a novel strategy to search for more excitonic insulators, enabling further studies to fully understand the rich physics of this new phase of matter.

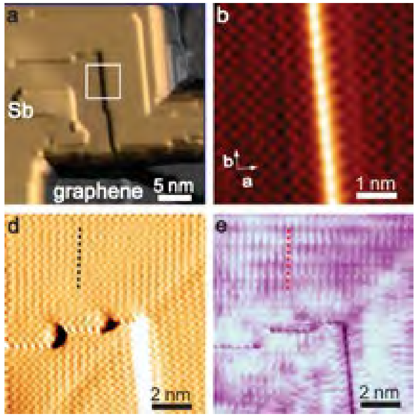
The study was published in *Nano Letters* in July 2019, vol. 19, iss. 8 (see publication 32, p97).

More at FLEET.org.au/exciton-insulator



From left, former PhD student Zhenwei Yun, CI Prof Xiaolin Wang, Scientific AI Dr David Cortie, PhD student Frank Fei Yun

Research Fellow Dr Zengji Yue (UOW)



Charge density wave without periodic lattice distortion on antimony nanoflakes

PROF KRIS HELMERSON

Leader, Research theme 3

Monash University

"FLEET puts us at the forefront of research and potential application of the non-equilibrium behaviour of materials."

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

Research outputs: 110+ papers, 4800+ citations, h-index 31 (Scopus)

RESEARCH THEME 3:

LIGHT-TRANSFORMED MATERIALS

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

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

- Short (attosecond), 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, p24) or to shift into a superfluid state (see Research theme 2, p28).

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 ultrashort 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...

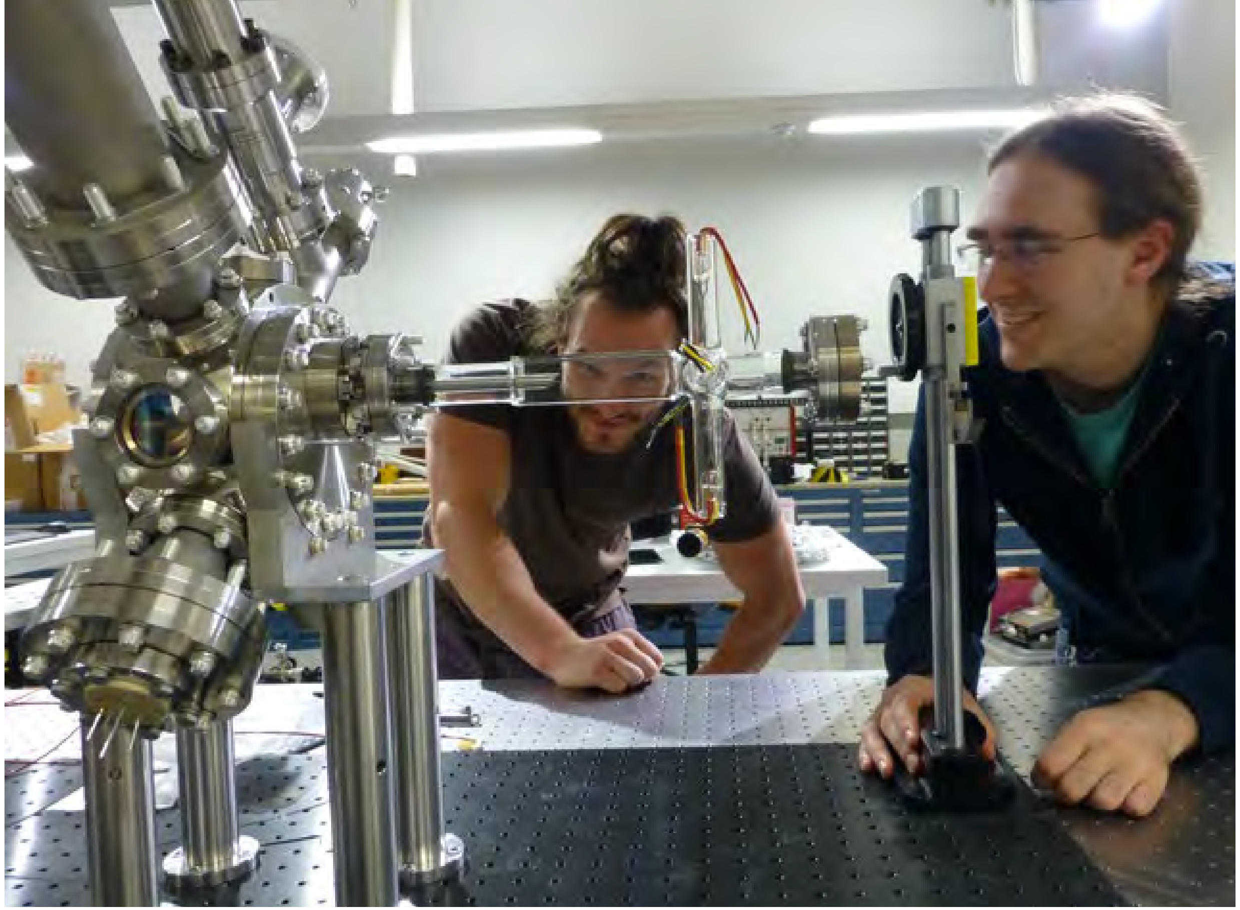
FLEET researchers cool atomic gases to only a few billionths of a degree above Absolute Zero – a billion times colder than interstellar space.

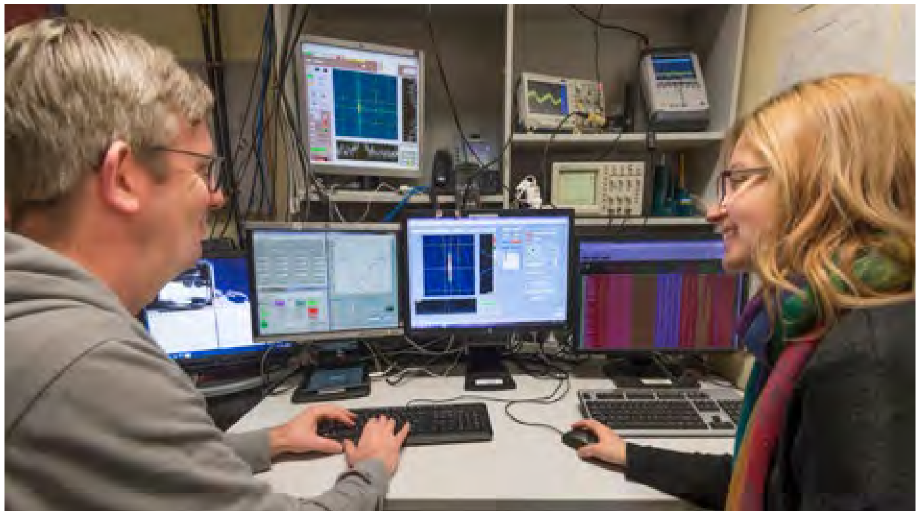
IN 2020, FLEET WILL:

- Demonstrate control of Floquet-Bloch bands
- Investigate topological states in the delta-kicked particle (Floquet) system with spin-orbit coupling
- Investigate lifetimes, impurities physics, and pairing in two-dimensional (2D) Fermi gases near p-wave Feshbach resonance
- Construct a quantum gas microscope facility to study dipolar atoms in optical lattices.

2019 HIGHLIGHTS

- Achieved negative temperature states (see case study, p34)
- Observed evolution of large-scale flow from turbulence (see case study, p34)
- Constructed a dedicated Bose-Einstein condensate (BEC) apparatus
- Measured optical Stark effect in WS_2 and MoS_2
- Measured pulse duration dependence.





Light-transformed materials: revealing fundamental physics at Monash University (above) and Swinburne University of Technology (right)

DEFINITIONS

Bose-Einstein condensate (BEC) A quantum state occurring at ultra-cold temperatures

dissipationless current Electric current that flows without wasted dissipation of energy

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

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

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

non-linear interactions Interactions in which forces acting on a system cause disproportionate results

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

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

CASE STUDY

ORDER FROM CHAOS

- Vortex studies first proof of decades-old theory.
- Seminal, seventy-year-old theory of turbulence experimentally verified for first time.

"Applications range from Jupiter's Great Red Spot to electron movement in superconductors."

A 2019 collaboration featuring FLEET researchers at University of Queensland (UQ) and Monash offered the first proof of a 70-year-old theory of turbulence.

"The studies confirm a seminal theory of the formation of large-scale vortices from turbulence in 2D fluid flow, where the large vortices emerge from an apparent chaos of smaller vortices," says author FLEET Chief Investigator Prof Matt Davis (UQ).

Turbulence, with its seemingly random and chaotic motion, has been called one of the 'great unanswered questions' of physics.

Fluids restricted to flow in two-dimensions can be observed in systems ranging from electrons in semiconductors, to the surface of soap bubbles, and atmospheric phenomena such as cyclones.

"One of the commonly observed features in such 2D flow is the formation of large-scale swirling motion of the fluid from the initially chaotic swirling motion typical of turbulent flow, such as Jupiter's Great Red Spot," said the Monash lead author, Shaun Johnstone ***(see memorial on facing page)***.

The famous Great Red Spot is an example of a 2D vortex.

More-familiar '3D' concepts of a vortex include the familiar twisting shape of a tornado, or the small whirlpool that forms at a bathtub plughole.

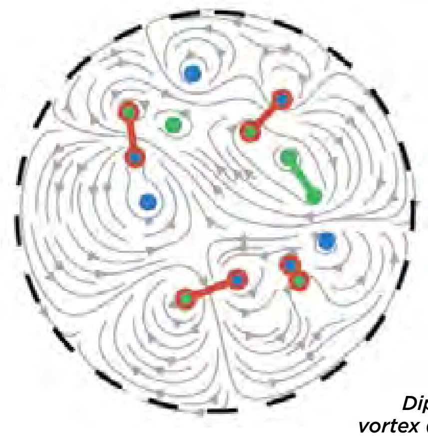
Other 2D vortices, in which there is no vertical movement, occur at the surface of liquids, or in atmospheric systems such as cyclones.

In fact, 2D vortices cover a vast range of systems, from the superfluid movement of neutrons on the surface of neutron stars to the Atlantic Ocean Gulf Stream to the zero-resistance movement of electrons in high-temperature superconductors.

For 70 years, our understanding of such 2D vortex systems has been governed by a seminal theory of turbulence, proposed in 1949 by the Nobel laureate Lars Onsager.

Onsager's theory states that as more energy is put into a chaotic mix of small vortices in a turbulent 2D system, the vortices rotating in the same direction will cluster to form larger, stable vortices.

That is, the system becomes ordered, rather than more chaotic, as more energy is applied, which is the opposite of what we would consider a 'normal' thermodynamic regime.



Dipole dominated vortex (Monash study)

In order to simplify his theory, Onsager considered a superfluid, which he stated would have 'quantised' vortices (that is, vortices with quantised angular momentum).

Both FLEET studies experimented using Bose-Einstein condensates (BECs), a quantum state that exists at ultra-low temperatures, and in which quantum effects become visible at a macroscopic scale.

The researchers created turbulence in condensates of rubidium atoms using lasers, and observed the behaviour of the resulting vortices over time.

Australian and international collaborators included the ARC Centre of Excellence for Engineered Quantum Systems (EQUS) and FLEET partner the Joint Quantum Institute, University of Maryland.

The results are relevant to non-equilibrium physics – the evolution of systems far from equilibrium, in particular, the development of coherent, large-scale flow from by putting energy into a turbulent system.

"The new studies are specifically relevant to the study of

Video outreach: Dr Shaun Johnstone explains mathematics of negative absolute temperatures

COLLABORATING FLEET PERSONNEL:

- Research Fellow Shaun Johnstone (Monash)
- Research Fellow Matt Reeves (UQ)
- Chief Investigator Matt Davis (UQ)
- Chief Investigator Kris Helmerson (Monash)

superfluids and superconductors," says co-author FLEET Chief Investigator Prof Kris Helmerson (Monash).

The two studies were published in *Science* in June 2019, vol. 364, iss. 6447 (see publications 14 and 22, p96).

More at FLEET.org.au/turbulence

We lost a dear friend in 2019, with the passing of Shaun Johnstone.

We are deeply saddened for the loss of this quietly brilliant, lovely young man, and for the grief of his wife, Melissa, family Phil, Judy, Grace and Mark, and his wide circle of friends in the physics community and beyond.

Shaun was a brilliant physicist, with outstanding grades, awards and results through school, undergraduate and PhD studies: his thesis on Bose-Einstein condensates was described as 'one of the best I've ever read' by one reviewer. Only months before Shaun suddenly suffered a seizure, caused by a stage 3 lesion on the brain, his research in quantum turbulence was published in the leading journal *Science* (facing page).

We also remember Shaun's generosity, both in giving back to his local community and family in Warrandyte, and equally evident in his worklife, for example in his support of the Monash undergrad physics community, optics society and the remarkable number of hours he spent in schools outreach on behalf of Monash and FLEET.

We saw and delighted in Shaun's love for physics, which saw him frequently explaining concepts to students, family, friends and colleagues. (We know he would have loved, and found hilarious, the physics lessons in his memorial service at Monash University.)

Shaun's clear, intuitive understanding of one such complex physics puzzle can be seen in his 'negative-temperature' video (for this and more, see FLEET.org.au/Shaun).

We remember his creativity, as evident in solving technical issues with experimental formation of quantum condensates as it was in beaming videos across the road to a friend's share-house, ripping a laser out of an early Bluetooth player to use as a laser pointer, or in fitting a killer sound system to a billy-cart, aged nine.

We miss you Shaun.

PROF XIAOLIN WANG

Leader, Enabling technology A

University of Wollongong

"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: 490+ publications, 11,500+ citations, h-index 53 (Scopus)

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 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 uses other atomically-thin materials, with its scientists seeking materials possessing the necessary properties for topological and exciton-superfluid states.

Did you know...

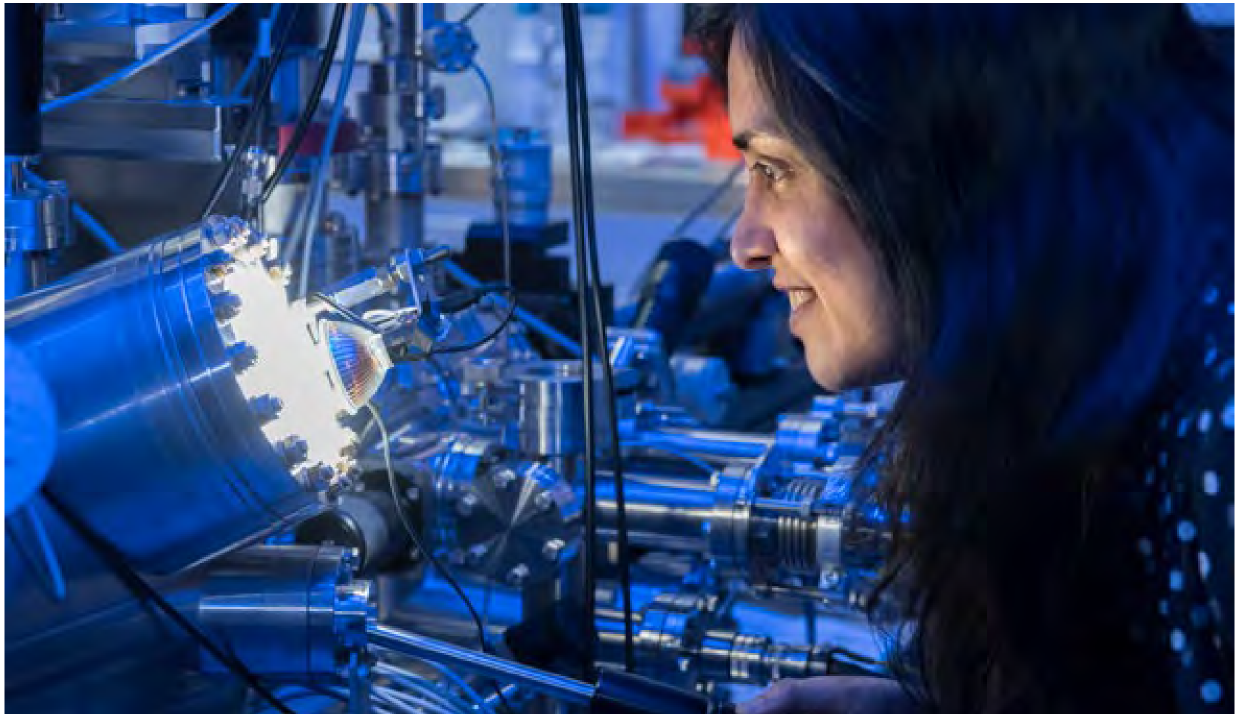
FLEET scientists use materials that are 'atomically thin' – only one layer of atoms thick. These materials are also referred to as two-dimensional (or 2D).

IN 2020, FLEET WILL:

- Synthesise and optimise wide-bandgap topological insulator
- Synthesise and optimise 2D ferromagnetic material with a high phase-change temperature
- Work with Research theme 1 to achieve quantum anomalous Hall effect (QAHE) in a new magnetic system
- Supply wide-bandgap 2D materials.

2019 HIGHLIGHTS

- Discovered 3D topological insulator crystals with bandgap much greater than room temperature and robust topological surface states up to 50 degrees Kelvin
- Predicted new class of materials – flat-band spin-gapless system – which is a new platform for the quantum anomalous effect
- Observed possible excitonic insulating state on antimony (Sb) nanoflakes (see p30)
- Fine-tuned topological insulator antimony telluride (Sb_2Te_3) by doping with iron (see p38)
- Made first observation of a native ferroelectric metal (see p26).



DEFINITIONS

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

ferromagnetic materials Material that can be magnetised

graphene A single 2D layer of carbon atoms

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

Above: Dr Semonti Bhattacharyya (Monash) studies electrical transport properties of topological materials

Right: Dr Daniel Sando (UNSW) synthesises and studies 2D topological materials

CASE STUDY

FINE-TUNING THE TOPOLOGICAL INSULATOR SB_2TE_3: JUST ADD IRON

Weiyao Zhao

Dr Zengji Yue

COLLABORATING FLEET PERSONNEL:

- Associate Investigator Zhi Li (UOW)
- PhD student Weiyao Zhao (UOW)
- Research Fellow Zengji Yue (UOW)
- Chief Investigator Xiaolin Wang (UOW)

Iron-doping of the topological insulator Sb_2Te_3 results in useful electronic and magnetic properties

FLEET researchers at the University of Wollongong found they could fine-tune the magnetic properties of the topological insulator antimony telluride (Sb_2Te_3) by 'doping' the material with iron.

The addition of iron changes the material's electronic structure significantly, with multiple response frequencies emerging, and both carrier density and carrier mobility reducing.

"This improved understanding of the effects of doping will be critical to inform future possible use of the material in low-energy electronics," explains project leader FLEET Chief Investigator Prof Xiaolin Wang (UOW).

Topological insulators' unique 'Dirac' surface states are attractive for electronic applications and potentially host a range of fascinating and useful phenomena.

In topological insulators such as antimony telluride, the surface electronic structure is 'entangled' with the internal (bulk) electronic structure and, consequently, both aspects need to be understood at the fundamental level.

Unresolved questions concerning the effect of metal doping of antimony telluride is related to one of the most fascinating transport properties in topological insulators: the quantum anomalous Hall effect (QAHE).

This describes quantisation of the transverse Hall resistance, accompanied by a considerable drop in longitudinal resistance.

FLEET is investigating the use of this ultra-low resistance to reduce the power consumption in electronic devices.

The study of magnetic-doped topological insulators seeks to find the optimal set of dopants, magnetic order, and transport properties in order to:

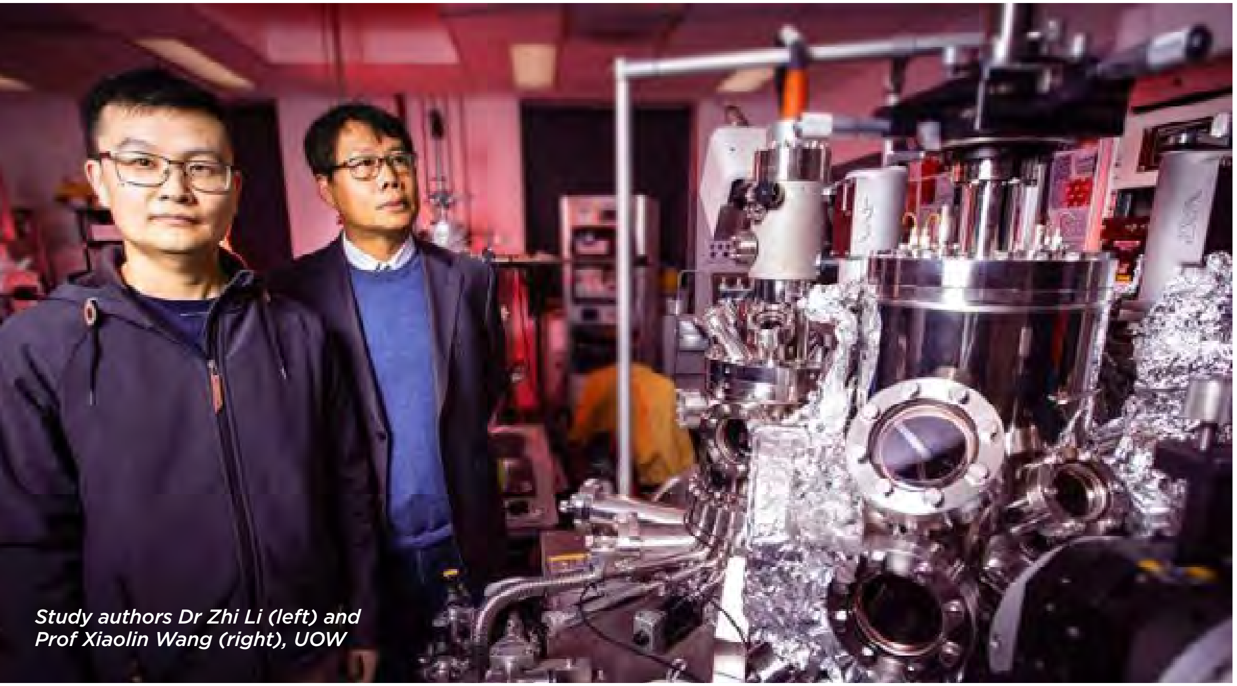
- Achieve a higher (near ambient) QAHE onset temperature
- Eliminate unwanted features in the electronic structure introduced by the transition-metal dopant that are detrimental to performance.

This study at UOW studied the electronic effects of doping high-quality Sb_2Te_3 crystals with iron, via magneto-transport experiments and complementary theoretical calculations.

This research is related to FLEET milestones 1.1.13, 1.1.14 and 1.1.15 (see p84).

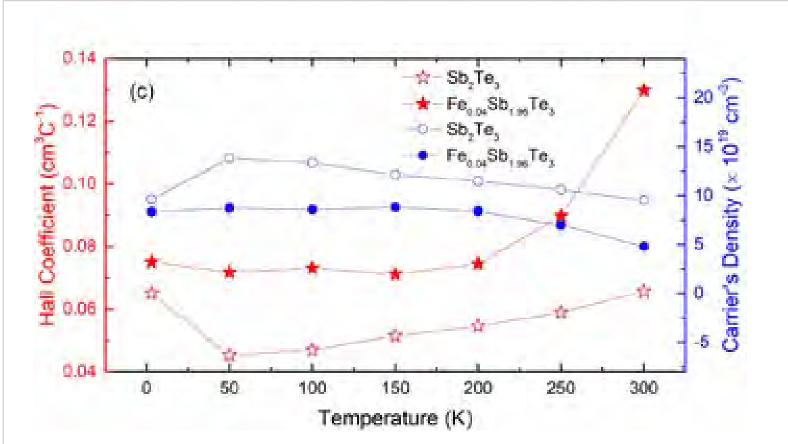
The study was published in *Physical Review B* in April, vol. 99, iss. 165133 (see publication 71, p98).

More at FLEET.org.au/iron-doping



Study authors Dr Zhi Li (left) and Prof Xiaolin Wang (right), UOW

Hall coefficient and carrier density as functions of temperature



> IT'S EXCITING to be at the forefront of research into new materials that could change the face of electronics. It's fast-paced and always changing – you have to be able to adapt and come up with new research directions quickly.
>
> **Dr Mark Edmonds**
> *FLEET Scientific Associate Investigator, Monash Univeristy*

Institute for Superconducting & Electronic Materials (UOW)

A/ 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: 100+ papers, 3000+ citations, h-index 31 (Scopus)

ENABLING TECHNOLOGY B:

NANO-DEVICE FABRICATION

FLEET's research sits at the very boundary of what is possible in condensed-matter physics. At the nanoscale, nanofabrication of functioning devices will be key to the Centre's success.

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

For example, atomically-thin topological insulators will need to be integrated with electrical gates to realise topological transistors. And atomically-thin semiconductors must be integrated with optical cavities to realise exciton-polariton condensate devices.

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

IN 2020, FLEET WILL:

- Achieve anomalous Hall effect (ideally quantum anomalous Hall effect (QAHE)) in a new magnetic system for Research theme 1
- Establish vdW-fabrication facilities and produce bi-layer structures for Research theme 2
- Synthesise and optimise a 2D ferromagnetic material with a high Curie temperature for Research theme 1.

2019 HIGHLIGHTS

- Established vdW-device fabrication facilities at RMIT, Monash and UNSW
- Developed lithographic techniques for nano-patterning artificial graphene
- Integrated transition metal dichalcogenides (TMDs) into distributed Bragg reflector cavities for exciton-polaritons.

Did you know...

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

Above: Nanofabrication connections: From left, Dr Jian-zhen Ou and A/Prof Lan Wang (RMIT), Prof Mingliang Tian (CAS High Magnetic Field Laboratory), Prof Xiaolin Wang (University of Wollongong)

DEFINITIONS

ferromagnetic materials Material that can be magnetised

heterostructure A structure in which two dissimilar materials are brought together at a controlled interface

quantum anomalous Hall effect (QAHE) A magnetic version of the quantum spin Hall effect, in which conducting edges carry currents in only one direction, and are completely without resistance

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

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

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

Left: Visiting collaborations, Dr Simon Granville (MacDiarmid Institute), with Dr Julie Karel at Monash University

CASE STUDY

MEET MOLYBDENUM, A POSSIBLE ACID-FREE ROUTE TO FUTURE HYDROGEN POWER

> THESE TYPES of discoveries show that the benefits of discovery-based research extend beyond FLEET's focused objectives, and will have impacts in a diverse range of fields.
>
> **Prof Michael Fuhrer**
> *FLEET Director*

A/Prof Nikhil Medhekar

Dr Yuefeng Yin

COLLABORATING FLEET PERSONNEL:

- Research Fellow Ali Zavabeti (RMIT)
- Research Fellow Yuefeng Yin (Monash)
- PhD student Hareem Khan (RMIT)
- Associate Investigator Jian-zhen Ou (RMIT)
- Chief Investigator Kouroush Kalantar-zadeh (UNSW/RMIT)
- Chief Investigator Nikhil Medhekar (Monash)

Molybdenum-based compounds could provide key to hydrogen production for future zero-emissions energy

A FLEET RMIT–Monash University collaboration opens a promising new route towards cost-effective hydrogen production.

The study, which combined experimental expertise at RMIT with theoretical modelling at Monash, discovered that ammonium-doped, hexagonal molybdenum oxide (MoO_3) displays extremely promising electronic and material properties for use as a catalyst in the production of hydrogen from water.

The resulting, improved electrochemical activity and exceptional stability offer excellent promise for this technique in future hydrogen production.

Hydrogen gas is a highly attractive alternative fuel, being carbon-neutral, free of environmentally-damaging by-products, and fully recyclable.

The technology's major challenge is the sustainable and efficient production of hydrogen gas.

Room-temperature, alkaline-water electrolysis is one of the most-promising hydrogen production technologies, despite the high energy requirements of the alkaline process (conversely, an acidic process has higher costs, but uses less energy).

And so the search is on for an economical catalyst with low energy requirements, and which is resistant to corrosion in an alkaline environment.

Molybdenum-based compounds are an emerging class of catalytic materials for hydrogen production in an acidic electrolyte, but most of these compounds lose catalytic performance and exhibit poor long-term stability in alkaline media.

Usually chemically inert, molybdenum oxide can be can be made more conductive via the introduction of oxygen vacancies, which also favours the adsorption of water molecules, hence lowering the energy required to separate out hydrogen.

"We studied the material's structure and hydrogen-evolution reaction rate at the labs at RMIT," says FLEET Research Fellow Dr Ali Zavabeti (RMIT).

These studies revealed that the key was to induce crystal phase transition via doping the material with ammonium ions. This alters the material's rectangular structure to a hexagonal crystal, which drastically improves stability.

This hexagonal crystal structure causes formation of tunnel-like pores in the material, which assist with stability, and also improve energy performance, by increasing the available reaction area and lowering hydrogen adsorption energy.

Electrons injected during the doping process also improve electron conductivity.

The team measured catalytic activity higher than any other studies of molybdenum compounds, with an exceptional stability that exceeded 40 hours of operation.

The researchers demonstrated that the formation of highly-ordered intra-crystalline pores of 2D molybdenum oxide enables efficient and extremely stable hydrogen-evolution reaction (HER) activity in an alkaline medium.

Compared to similar studies, the researchers' molybdenum catalyst demonstrated significantly-enhanced HER activity, confirming that the doping-driven formation of highly-ordered intra-crystalline pores on 2D materials could be a feasible design strategy for high-performance, non-metal catalysts for alkaline hydrogen evolution.

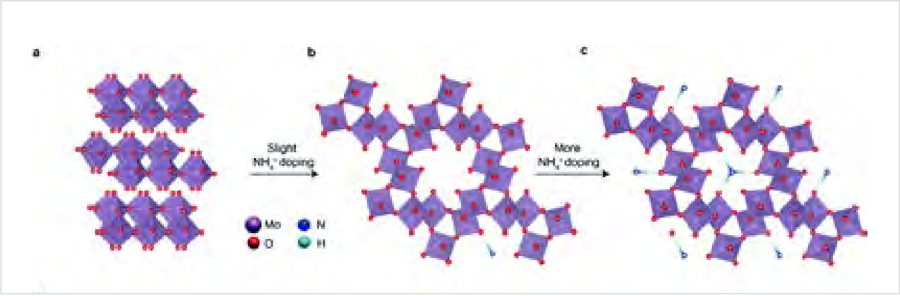
The interdisciplinary study paired RMIT experimental expertise with theoretical modelling at Monash.

"Our theoretical calculations identified active atomic sites for hydrogen adsorption, thus revealing the physical origin of the improved catalytic activity," said FLEET Research Fellow Dr Yuefeng Yin (Monash).

This addresses FLEET milestone 1.16 (see p84).

The study was published in the *Journal of Materials Chemistry A* in January 2019, vol. 7, iss. 1 (see publication 18, p96).

More at FLEET.org.au/molybdenum



Crystal structure of molybdenum-trioxide (MoO_3) doped with NH_4^+ ions, with regular orthorhombic (rectangular) structure altered to hexagonal

FLEET Research Fellow Dr Ali Zavabeti (RMIT)

ENABLING TECHNOLOGY B

COLLABORATE

PhD student Zeb Krix (UNSW) studies theory of magnetic fields on artificial graphene with collaborators including visiting AI A/Prof Shaffique Adam (National University of Singapore)

03

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

FLEET
COLLABORATIVE EFFORTS

2 VISITS BY INTERNATIONAL STUDENTS AND ECRs

15 FLEET MEMBERS VISITING PARTNER ORGANISATIONS

21 VISITS BY INTERNATIONAL COLLABORATORS

6 NEW RESEARCH COLLABORATING ORGANISATIONS ESTABLISHED

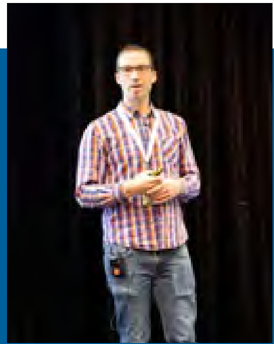
133 INTERNATIONAL TRIPS MADE FOR RESEARCH COLLABORATION

31 **NEW ORGANISATION LINKS FOR TRAINING AND OUTREACH** ESTABLISHED

5 **END-USER** RELATIONSHIPS ESTABLISHED

Dr Dmitry Efimkin (Monash) and Prof Elena Ostrovskaya (ANU)

Prof Mingliang Tian



Prof Justin Hodgkiss

A/Prof Nicola Gaston

Dr Kirrily Rule

More information FLEET.org.au/partners

> AS a partner investigator I hope to help facilitate neutron scattering experiments at ANSTO for FLEET researchers as a valuable tool for investigating their materials.
>
> **Dr Kirrily Rule**
> FLEET Partner Investigator, ANSTO

NEW PARTNERS

FLEET added two new partner organisations in 2019, and four new Partner Investigators, expanding the Centre's research and science, technology, engineering and maths (STEM) relationships and available expertise. These new agreements bring FLEET's Australian and international partners to 18 (see chart below). Two of our new PIs presented at FLEET's 2019 annual workshop, sharing research directions and best practice in outreach and community engagement.

The MacDiarmid Institute is New Zealand's premier material science research centre, and shares FLEET's search for future low-energy electronics via the development of novel materials and devices. New Partner Investigators, and MacDiarmid Co-Directors, Prof Justin Hodgkiss and A/Prof Nicola Gaston will oversee a broad partnership including fundamental new materials research and a range of initiatives in STEM outreach and equity in science.

The Chinese Academy of Science's (CAS's) High Magnetic Field Laboratory (Anhui, China) studies low-dimensional electronic systems and artificial nanostructures. FLEET's new Partner Investigator, lab Vice-Director Prof Mingliang Tian, will work with FLEET Chief Investigator A/Prof Lan Wang (RMIT University) to study two-dimensional (2D) magnetic materials, vdW ferromagnetic heterostructures and topological condensed-matter systems.

HOSTING SCIENTIFIC MEETINGS

FLEET supported significant international and Australian conferences in 2019, which was bookended by major, FLEET-hosted conferences at the end of 2018 (ICON2D-Mat) and beginning of 2020 (ICSCE).

With new partner organisation the MacDiarmid Institute (NZ), FLEET co-organised the **Conference on Signature of Topology in Condensed Matter** in Italy, working closely with the International Centre for Theoretical Physics.

Almost 120 researchers gathered to discuss spin and strong-electron correlations at UNSW's biennial **Gordon Godfrey Workshop**, which was sponsored by FLEET and meshed with city-wide efforts to highlight Australia's strength in physics.

> MC² events have successfully brought together and expanded networks in the thriving condensed-matter community in Victoria, with FLEET showing leadership in this space.
>
> **Prof Jared Cole**
> *FLEET Chief Investigator, RMIT*

In 2019 FLEET has thrown further support behind the new **Melbourne Condensed Matter Community** (MC²) events, jointly founded by FLEET's Jared Cole (RMIT) with Stephan Rachel and Andrew Martin (University of Melbourne). So far, four workshops organised by FLEET members or collaborators (at Swinburne, Monash, RMIT, and the University of Melbourne) have each brought together over 50 researchers for a full day of talks by people working across theoretical, computational and experimental condensed-matter physics. In addition, monthly MC² colloquia, which alternate between RMIT and the University of Melbourne, have featured several FLEET speakers.

HOSTING RESEARCH SEMINARS

FLEET's live-streamed seminars help share research results across the Centre, keeping members informed on latest FLEET research, and enhancing inter-node collaboration.

Early-career researchers presenting the seminars gain valuable presentation experience, and benefit from immediate feedback on their research from diverse Centre members.

In 2019, FLEET-wide live-streamed seminars were presented by:

- Dr Dan Sando (UNSW)
- Dr Jackson Smith (RMIT)
- Dr Maciej Pieczarka (ANU)
- Dr Agustin Schiffrin (Monash University).

The 19 research seminars that FLEET hosted by visiting researchers at ANU, Monash, UNSW and RMIT (see image), exposed Centre members and affiliates to diverse research from around the world.

ESTABLISHING A COLLABORATIVE CULTURE ACROSS THE CENTRE

- First research workshop organised by early-career researchers (ECRs) and students
- Cross-node publications increased by 18% (from 7 to 11)
- Four FLEET-wide, live-streamed seminars run in 2019 (target 10)
- New $50,000 grant created for collaborative projects with partner MacDiarmid Institute
- New $20,000 funding pool established for ECR collaborative grants with partner organisations
- Christmas in July social event, Melbourne nodes
- 30 trips by ECRs to collaborating organisations
- Members' profiles spotlighted at annual workshop
- Environmental-impact taskforce formed, instigated by ECRs.

> I LOVE the scientifically-inspiring FLEET community – everyone is so open to discussions and collaborations. We all feel we are part of something bigger, and contributing to solving a larger problem. It's nice to feel like you have a home within the Australian physics community. It's exciting, challenging and cutting edge, and the physics is awesome!
>
> **Dr Julie Karel**
> *FLEET Scientific Associate Investigator*
> *Monash University*

See FLEET.org.au/2019collab for list of 2019 workshops and seminars.

FLEET ENVIRONMENTAL GROUP

While FLEET's aim is to reduce the world's ICT power consumption, we also know that some of the work we do today is having a detrimental effect on tomorrow's environment.

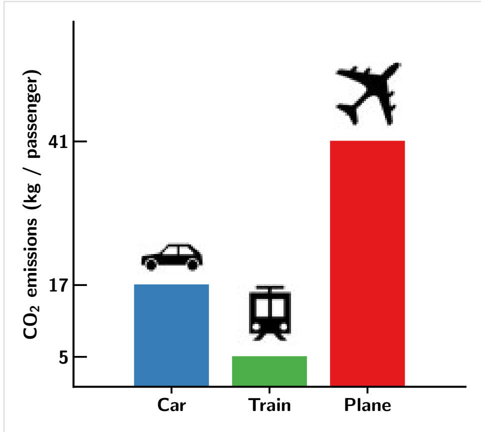
Initiated by FLEET ECRs, the Centre's Environmental working group is taking a microscope to the environmental impact of FLEET.

One early output has been a tool to calculate and compare emissions from different forms of transport to scientific meetings, which will be made available to others. The graphic (right) compares emissions travelling between Sydney and Melbourne.

Tool developers, Environmental group leader Dr Jackson Smith (RMIT) and Dr Martin Cyster (Exciton Science Centre) will promote the tool after taking the train to a Brisbane conference early in 2020. By showcasing such examples, including members who rode or took the train to the Centre's annual workshop in Lorne, the group hopes to inspire other academics and physicists to consider their own environmental impact.

> COLLABORATIONS between theorists and experimentalists are one of the ways that FLEET improves the work of all members.
>
> **Prof Laurent Bellaiche**
> *FLEET Scientific Associate Investigator, University of Arkansas*

FLEET Environmental team leader Dr Jackson Smith



Examining the carbon imprint of academic travel: Calculation tool developed by Dr Jackson Smith (FLEET) and Dr Martin Cyster (ARC Centre of Excellence in Exciton Science)

WORKING WITH OTHER SCIENCE ORGANISATIONS

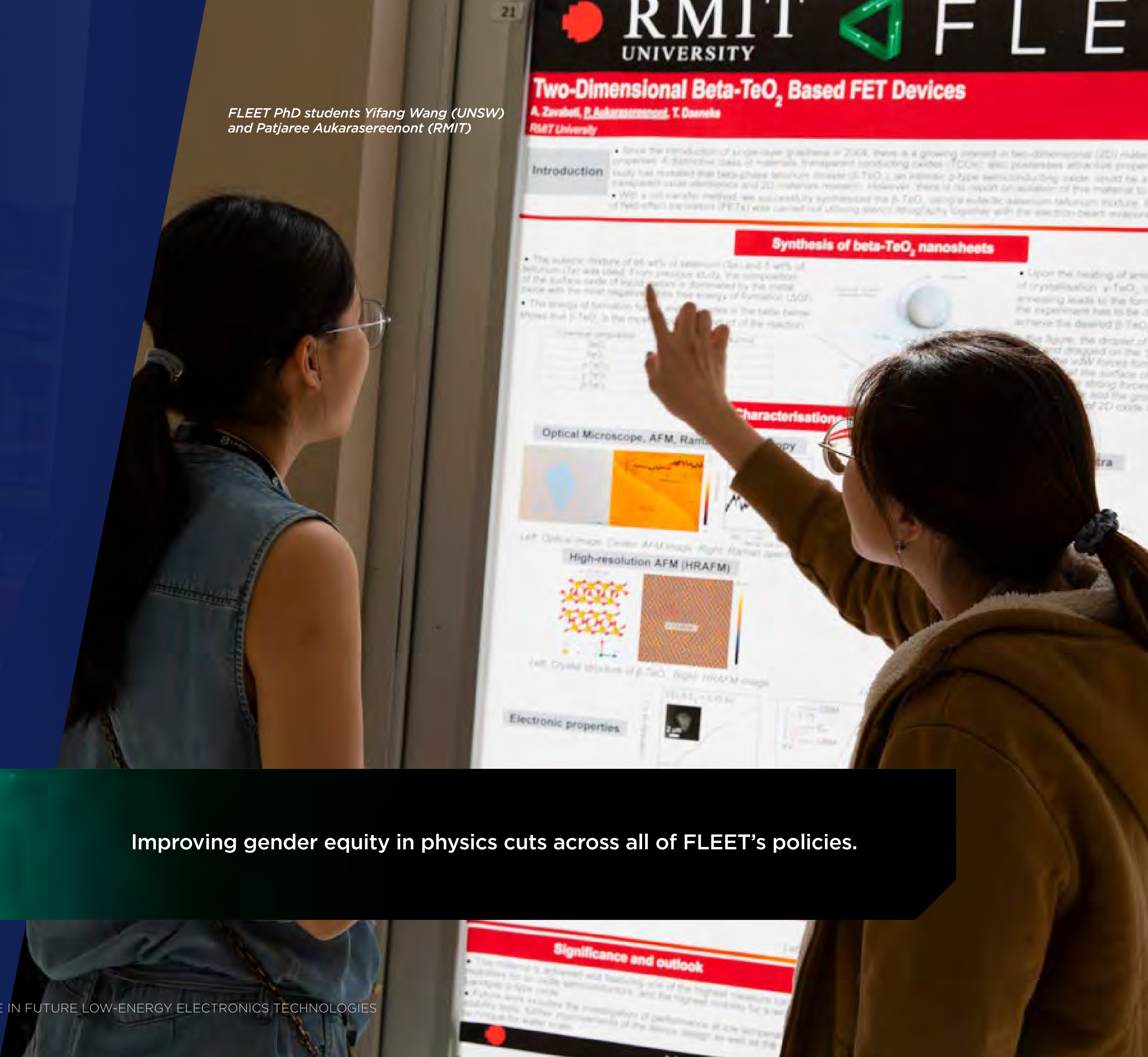
FLEET continues to build links with other science organisations within Australia to further the reach of science, advance equity issues and develop future leaders, for example:

- Sponsoring childcare at the annual Science Meets Parliament, with Science and Technology Australia (STA)
- Running pitch training with two other ARC Centres of Excellence
- Co-sponsoring Physics in the Pub with three ARC Centres of Excellence and Australian Institute of Physics (AIP)
- Working with the Australian Museum to run stall during Sydney Science Festival (see case study p68)
- Talking to the public at Melbourne Knowledge Week, run by City of Melbourne
- Presenting at a multi-ARC centre workshop
- Running the annual Idea Factory early-career researcher training workshop with ARC Centre of Excellence for Engineered Quantum Systems (EQUS)
- Assisting with Mentoring and Guidance in Careers (MAGIC) workshop for women and gender-diverse ECRs
- Linking with the Monash Energy Institute to co-organise industry-engagement events.

In addition, FLEET worked with professional bodies to present Centre science to industry-engaged audiences, including the Institute of Electrical and Electronics Engineers (IEEE) and Engineering Australia (Sydney) and Royal Society of Victoria (Melbourne).

The Centre also worked closely with Monash Tech School, running lab tours for local school students, and with John Monash Science School to develop a new Year 10 FLEET science unit (see p69).

EQUITY



FLEET PhD students Yifang Wang (UNSW) and Patjaree Aukarasereenont (RMIT)

04

Improving gender equity in physics cuts across all of FLEET's policies.

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

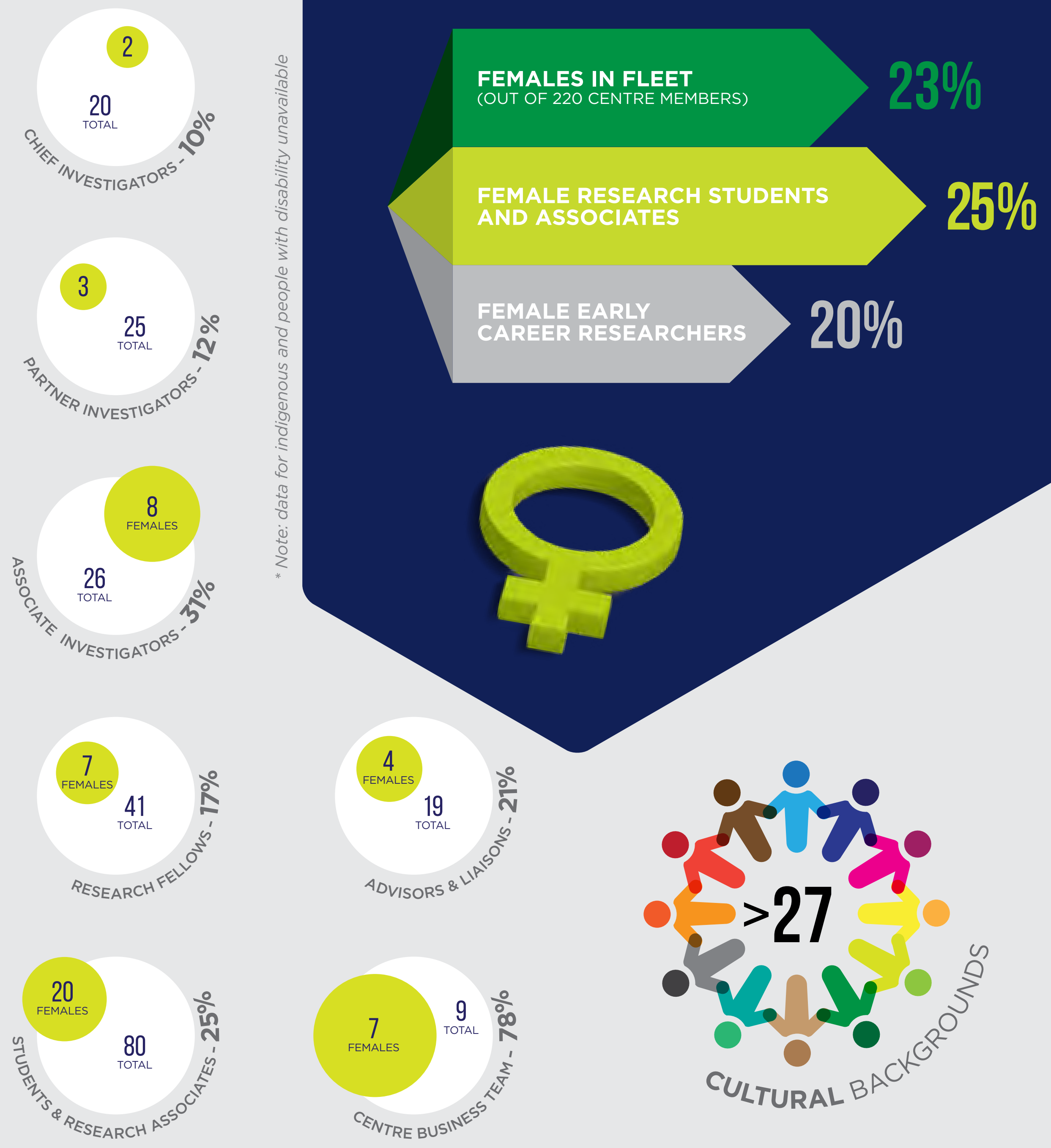
Research confirms that diverse teams do better science. We know that by improving our performance with respect to gender equity and diversity, we are not only doing what's fair, we will also improve the effectiveness of our research teams.

Change does not 'just happen'. We have realised that we need to set and enforce targets, in particular, in recruitment. The necessary change will not happen 'organically'.

> WE ARE creating a respectful workplace that is free from discrimination and values the contributions of all members.
>
> **Prof Michael Fuhrer**
> Director, FLEET

FLEET IS:

- Fostering a culture of equity and inclusiveness
- Raising members' awareness through training on equity, diversity and inclusion topics
- Increasing diversity among all cohorts of researchers
- Establishing career-support initiatives for women in FLEET
- Operating a women-specific mentoring network **(see p63)**.



Discussions during poster session, FLEET annual workshop

FLEET's target in 2019 was 20% female researchers across all cohorts. We have maintained our 2018 numbers of female higher degree by research (HDR) students (24%) and advisers and liaisons (21%). Women in FLEET Fellowships and Strategic Fund grants have allowed us to increase the number of female research fellows to 17% (from 7% in 2018) and associate investigators to 31% (from 17% in 2018).

The Centre's goal for 2020 is 25%, and ultimately to reach 30% representation of women at all levels.

However, we are still below our overall target, so much work remains to be done.

A particular focus for the Centre must be to increase the representation of women in senior roles.

FLEET's recruitment in its first two years drew from the existing physics pool, which unfortunately has a relatively low percentage of women. FLEET's Women in FLEET Fellowships **(see case study, p54)** and strategic grants have allowed the Centre to begin to increase the percentage of women at early-career researcher (ECR) and associate investigator levels, above the average in physics.

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 p53)** will help us maximise the chance of success for these changes.

> IT WAS really heart-warming to learn, from verbal responses to our equity and diversity survey, that our members are grateful to be part of a Centre that acknowledges the importance of equity and diversity, and that our newest members find FLEET's efforts in this space "extremely amazing". We must be doing something right...
>
> **Prof Elena Ostrovskaya**
> *Chair, Equity and Diversity Committee*

IN 2019, FLEET HAS:

- Increased the representation of women across the Centre, from 16% to 23%, with:
  - Six new female associate investigators (out of 13)
  - Three Women in FLEET PhD scholarships
  - Three Women in FLEET Fellowships **(see p54)**
- Shared our learnings, publishing a women-only recruitment case study
- Established career-support initiatives
- Co-supported scholarships for Women & Leadership Australia's Leading Edge program, sponsoring seven successful FLEET participants
- Provided a carer's support fund and childcare at FLEET meetings
- Established a women-specific mentoring network, with 13 female mentors
- Welcomed eight new external female mentors
- Formed new, long-term partnerships with ANU to support MAGIC and DCA programs **(see case study, p55)**
- Improved members' access to equity resources and information via web, intranet and monthly newsletter articles, including FLEET and external programs, and Centre policies
- Identified challenges and recorded member experiences, via a comprehensive equity and diversity survey **(see case study, p53)**.

Did you know...

FLEET has people of 27 different nationalities and cultural backgrounds across all levels of the Centre.

IN 2020, FLEET WILL:

- Implement priorities informed by a 2019 comprehensive survey of Centre members (see right)
- Provide an avenue for easy feedback about any experiences of an exclusive environment or discrimination
- Implement FLEET-wide cultural awareness (working with the Diversity Council of Australia)
- Improve awareness of equity and diversity training and education opportunities (including via the internal newsletter and website)
- Increase the visibility of women in FLEET
- Expand our mentoring and training programs for ECRs and HDR students
- Offer opportunities for inter-node social interactions and community building, to develop understanding and acceptance across cultural and other barriers.

CASE STUDY

LISTENING TO OUR MEMBERS: SURVEYING CHALLENGES AND EXPERIENCES

Improving the situation of women in physics calls for complex cultural challenges. We must be sensitive to potential challenges of resistance and backlash.

Following the 2018 survey, FLEET conducted a second comprehensive cultural survey of its members to determine attitudes to gender equity. An impressive 53% of members responded, revealing that:

- Over 80% found their workplace inclusive and respectful
- 90% were aware of FLEET equity and family-friendly policies and initiatives
- 90% agreed that FLEET values equity and diversity
- 90% were aware of opportunities FLEET provides to help make it easier to be a woman in science, technology, engineering and maths (STEM)
- Membership in the Ally network (staff who are understanding of and empathetic towards the lesbian, gay, bisexual, transgender, intersex and queer (LGBTIQ) community) has increased 50% from 2018.

We found that discrimination and harassment are very rare within the Centre.

Understanding members' attitudes will let FLEET frame equity initiatives in a way that maximises their chances of success. Getting our members 'on board' also improves the chances of this necessary cultural change outlasting the Centre.

We will continue to ensure that all FLEET members understand what we are doing and why, and are empowered to speak up about difficulties.

More at FLEET.org.au/equity

Peggy Zhang, Centre workshop

BEING A mum of two little boys makes business travel difficult, either with or without kids. FLEET's carer grant allowed me to bring my husband to care for our kids at FLEET's annual workshop. Along with on-site childcare, this meant I could participate fully in the workshop, networking with peers instead of worrying too much about the little ones.

Dr Peggy Qi Zhang
FLEET Research Fellow, UNSW

Image left, family at FLEET annual workshop

EQUITY

CASE STUDY

SHIFTING THE DIAL: WOMEN IN FLEET FELLOWSHIPS

FLEET's goal is to achieve 30% representation of women at all levels across FLEET.

To begin moving towards this goal, we needed innovative approaches that would allow us to begin 'shifting the dial'.

One innovative initiative that has met with success is FLEET's new 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 these fields. This was the first such initiative for a Centre funded by the Australian Research Council.

Before 2019, FLEET's recruitment efforts drew from the existing pool of talent in physics, engineering and material science, which have a relatively low percentage of women.

The Fellowships targeted early-career researchers who identify as female and had research interests aligning with any research areas within FLEET. The Fellowships also allowed for improved flexibility in the location and type of position on offer; for example, applicants could nominate investigators they want to work with.

The number of applications was extremely high, indicating that the Fellowships successfully located talent overlooked in previous, more tightly targeted searches. In fact, FLEET received almost 70 applications – twice as many women as we had reached with all 15 previous, targeted searches together!

The result was three new Women in FLEET Fellows.

> IN AN environment where initiatives aiming to get girls into STEM outnumber practical initiatives to keep women in science careers, the Women in FLEET fellowship is a refreshing initiative addressing much-needed structural change.
>
> **A/Prof Nicola Gaston**
> *FLEET Partner Investigator,*
> *Co-Director, MacDiarmid Institute NZ*

More at FLEET.org.au/women-in-fleet

FLEET's first three Women in FLEET Fellows: Dr Semonti Bhattacharyya (Monash), Dr Peggy Qi Zhang (UNSW), Dr Iolanda Di Bernardo (Monash)

CASE STUDY

NEW PARTNERSHIPS WITH STEM-EQUITY CHANGE AGENTS: MAGIC AND DCA

Two significant, long-term partnerships will progress FLEET's equity goals as well as supporting change in the Australian STEM community.

FLEET was pleased to be a sponsor for this year's annual MAGIC mentoring workshop, which provides mentoring and skills development for early-career female and gender-diverse researchers in maths and physical science.

FLEET's three-year partnership with Mentoring and Guidance in Careers (MAGIC) will support the annual, five-day MAGIC workshop at ANU, which is aimed at developing skills and networks for Australian ECRs who identify as female or gender diverse.

FLEET ECRs Dr Iolanda Di Bernardo and Dr Chi Xuan Trang (both from Monash University) attended. FLEET Equity and Diversity Committee Chair Prof Elena Ostrovskaya facilitated a session on career goals and aspirations, and featured on the mock interview panel that helped hone participants' industry-engagement skills.

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

Members may choose any training and development opportunity of their choice, including face-to-face sessions, webinars, or online modules. FLEET's new five-year membership of Diversity Council Australia (DCA) introduces a wide toolkit of knowledge programs, research, practical tools and events for our members.

The FLEET website, intranet and newsletter provide links to resources and opportunities available at individual nodes, as well as those provided by DCA.

Partnerships such as these are part of FLEET's effort to provide career support for ECRs, in particular under-represented women, in FLEET and in the wider Australian science community.

FAMILY-FRIENDLY EVENTS

FLEET endeavours to lead change within the Australian science community. We believe that all conferences and workshops must work for researchers with families, rather than the other way around.

FLEET's annual workshops are unusual in that families and partners are welcomed to all meals and social events, and free on-site childcare is provided for all delegates.

Involving families and children at FLEET's workshops has transformed these events. In particular, the presence of children at scientific poster sessions and social events created a unique and enjoyable atmosphere. FLEET's annual workshop this year included 48 partners and family members, including 25 children (19 in childcare).

Free on-site childcare is also provided at conferences and events supported by the Centre, allowing their parents to participate fully in lectures and seminars. FLEET only funds events that consider equity and diversity in their speaker selection, family-friendly policies and assistance, and overall event organisation.

See the Equity and Diversity Committee **(p87)**.

EDUCATION

Honing key pitch skills in the halls of Parliament: FLEET PhDs Hareem Khan (RMIT), Oliver Stockdale (UQ) and Research Fellow Dr Semonti Bhattacharyya (Monash)

05

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

FLEET **EDUCATION AND TRAINING COMMITMENTS**

7
RESEARCH AND PROFESSIONAL DEVELOPMENT WORKSHOPS

742
TOTAL NUMBER OF CENTRE MEMBERS ATTENDING TRAINING WORKSHOPS

516
TOTAL NUMBER OF NON-CENTRE MEMBERS ATTENDING TRAINING WORKSHOPS

18
RESEARCH SEMINARS HELD

4
MENTORING PROGRAMS

10
RESEARCH WORKSHOP & CONFERENCES ORGANISED, 1 OVERSEAS

4
FLEET-WIDE COLLOQUIA HELD

PhD student Bernard Field (Monash) asking questions at FLEET annual workshop

> THE CENTRAL organisation of training and development within FLEET encourages a lot of great activities that it wouldn't be possible to do without the Centre.
>
> **Prof Matthew Davis**
> *Chair, FLEET Education and Training Committee*

CASE STUDY

BUILDING FUTURE SCIENCE LEADERS: FLEET DEVELOPMENT PROGRAMS

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

The Centre currently supports 51 higher degree by research (HDR) students and 43 postdoctoral researchers with another 29 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 ECRs have welcomed leadership roles within the Centre, including ECRs who have:

- Organised the Centre's midyear ECR workshop
- Instigated a social media task force
- Pressed for and led a new environmental task force
- Taken on the role of chairing Centre governance committees.


Tinghe Yun (Monash)


Yifang Wang (UNSW)


Matt Gebert (Monash)

Did you know...

About 95% of STEM PhD graduates end up working in jobs outside academia.

FLEET TRAINING PROGRAMS 2019

- Idea Factory entrepreneur program (with the ARC Centre of Excellence for Engineered Quantum Systems (EQUS) and CSIRO, see p60)
- Pitch training (with the ARC Centre of Excellence in Exciton Science (ACEx) and the ARC Centre of Excellence for Mathematical and Statistical Frontiers (ACEMS), held at Swinburne)
- **YouRforum**: Got PhD, What Next? (RMIT, see p61)
- Advanced thin-film X-ray diffraction (UNSW) – facilitated by ECR Dan Sando
- Working effectively with your PhD supervisor – facilitated by CI Nagy Valanoor
- Annual workshop tutorials: research in the semiconductor industry, topological insulators, unconscious bias.
- 7 scholarships for FLEET members to attend Women & Leadership Australia Leading Edge professional development program
- Ongoing partnership with MAGIC workshop – mentoring and guidance for women in STEM
- Supported equity and diversity training, via new partner, Diversity Council Australia (DCA) (see p55).

CASE STUDY

LINDAU NOBEL MEETING

Three FLEET ECRs attended the 69th Nobel laureate meeting in Lindau, Germany, forming an impressive 30% of Australia's ten-person delegation, selected and led by the Australian Academy of Science: Dr Eli Estrecho (ANU), Hareem Khan (RMIT) and Dr Matt Reeves (UQ), pictured right.

The 2019 meeting focused on physics, and a number of senior FLEET members were among the laureates. Our ECRs were pleased to connect with Centre advisers and partners Prof Wolfgang Ketterle, Prof William Phillips, and Sir Kostya Novoselov.

FLEET's participants were thrilled to meet Nobel laureates prominent in the particular field of research the ECRs work in. for example, Eli Estrecho, who works in Bose-Einstein Condensates, discussed his work with the first person to ever make one!

Just as valuable was discovering common experiences with both senior laureates and other early-career researchers.

> THE LINDAU meetings definitely regenerated my enthusiasm and confidence for working in science. Talking to fellow young scientists made me realise that almost every one of us, especially the postdocs, have the same struggles. Most importantly, talking to the Nobel laureates and hearing their lectures and discussions supports this experience, which they also experienced during their early career, yet they all have overcome it.
>
> **Dr Eli Estrecho**
> *FLEET Research Fellow, ANU*

Above and left, FLEET attendees at Lindau Nobel Meeting, and photobombing Nobel laureate discussions

CASE STUDY

BUILDING FUTURE ENTREPRENEURS: IDEA FACTORY

It's not easy to convince a group of PhD students and early-career researchers to take three days away from their research to complete a training course.

Yet this type of training can provide incredibly valuable skills for these researchers in their future careers and endeavours.

At Idea Factory 2019, a joint project with FLEET and the ARC Centre of Excellence for Engineered Quantum Systems (EQUS), 30 researchers came together to complete a CSIRO-developed course in industry engagement and entrepreneurship.

In small, multidisciplinary groups, attendees pitched a product, learning how to take a product to market and presenting to a panel of entrepreneurs and high-school students.

Many researchers were surprised to find it was more daunting and more difficult to present to the high-school students than to the seasoned entrepreneurs! In this exercise, school students represented the role of investors who may not know a lot about physics, so it was necessary for the groups to communicate simply and effectively with the judging panels.

FLEET Research Fellow Dr Daisy Wang (UNSW)

Discussions at Idea Factory 2019: Matt Davis (UQ), Matt Gebert (Monash) and Frank Fei Yun (UOW)

> IDEA FACTORY 2019 helped me realise what's important about taking a product to market, and how to engage with potential customers. The challenge of communicating a research project, and deciding which vital aspects will engage your audience, is a valuable and often overlooked skill. The additional diffculty of communicating this without using any scientific details was a real challenge. It was refreshing to remind myself what is important about the research I do, and how it is useful for society.
>
> **Oliver Stockdale**
> *FLEET PhD student,*
> *University of Queensland*

CASE STUDY

YouRforum: GOT PHD WHAT NEXT?

Jobs in many of the fastest-growing industries require science, technology, engineering and mathematics (STEM) skilled professionals

The Young Researchers Forum, aka **YouRforum** was created by FLEET COO 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.

The program's 'Got PhD, What Next?' forum focuses on post-PhD careers, inspiring PhD students to plan their careers as future leaders in both academia and industry: A panel of diverse STEM PhD graduates share their unique career journeys and lessons learnt, followed by a Q&A session from the audience.

Discussions have included how to obtain a postdoctoral position, winning research grants, and overcoming challenges of the PhD journey, as well as discussions on difficult career choices and breaking barriers.

Statistics show that the majority of STEM PhD graduates will end up in careers outside of academia.

Students therefore need to develop a diverse skills base to enhance their future job opportunities, ensuring readiness for whichever career path they pursue.

FLEET took up **YouRforum** in 2017, offering the training workshop to Centre members and other interested STEM PhD students.

Over five 'Got PhD, What Next?' workshops, students have met more than 40 academics, entrepreneurs and research managers, including professionals in business development, finance and legal fields – all of whom are PhD STEM graduates. The 200+ graduate students and ECR attendees have gained practical tips and advice from those who have been there, done that.

One of the most common pieces of advice from panellists has been: don't underestimate transferable skills gained from the PhD, which can be applied in various professions regardless of fields. These include collaboration, innovative approach to solving problems, creative thinking, time management and effective communication to a wide audience.

> A COMMON piece of advice from **YouRforum** panellists has been that having a growth mindset and an active learning attitude is one of the key ingredients in overcoming challenges in this ever-changing job landscape.
>
> **Dr Dianne Ruka**
> *FLEET Education and Training Coordinator*

YouRforum panel from left: Prof Madhu Bhaskaran (RMIT), Dr Tien Huynh (RMIT), Dr Torben Daeneke (RMIT), Dr Tich-Lam Nguyen (FLEET)

EDUCATION

CASE STUDY

HONING THE ART OF THE PITCH: FAMELAB

It can be intimidating for young researchers to put themselves forward as public speakers, but the rewards are significant.

Speaking to a non-academic audience hones communication skills that are transferable from academia to any other field, preparing ECRs for wherever their career might take them.

FLEET encourages and supports ECRs to take up that challenge, and this year had two ECRs put themselves forward, successfully, within the national FameLab competition.

FLEET Research Fellows Dr Semonti Bhattacharyya (Monash) and Dr Samuel Bladwell (UNSW) made their respective state finals, with Sam going on to participate in the national finals in Perth.

FameLab challenges young researchers to explain their work in no more than three minutes, pitching to a general audience without any slides, and with only the props that can be carried with them onto the stage.

On top of these challenges, presenting on fundamental physics makes it even more important to find a 'hook' to effectively engage the audience, alongside 'competition' that might be curing cancer or saving endangered animals!

Semonti and Sam learnt to effectively use analogies and humour to convey their research, both making excellent presentations.

IDENTIFYING OPPORTUNITIES FOR MEMBERS TO BE RECOGNISED:

- Seven members presented at FameLab (see left), Pint of Science, Engineers Australia and Royal Societies
- Three ECRs attended 2019 Lindau Nobel Laureate Meeting (see p59) – two more nominated for 2020
- Three ECRs attended Science Meets Parliament (see p72)
- Dianne Ruka recognised for exceptional service to the Faculty of Science (Monash).

FLEET ECRs at Science Meets Parliament (see p72), above with Victorian MP Clare O'Neil, and below from left Semonti Bhattacharyya (Monash), Hareem Khan (RMIT), Oliver Stockdale (UQ)

> OK I WILL teach you quantum mechanics in 30 seconds.
>
> **Dr Semonti Bhattacharyya**
> FLEET Research Fellow
> Monash University
> FameLab state final

Julie Karel (Monash) and Alex Hamilton (UNSW)

> MY MENTOR and I have already had insightful conversations about translation of research to commercial products. I'm looking forward to more of these engaging conversations in the future.
>
> **Yonatan Ashlea Alava**
> *FLEET PhD student, UNSW*

FLEET MENTORING

Centre mentoring programs:

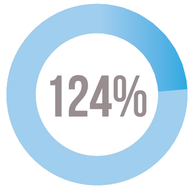
- Early-career researcher mentoring
- Industry mentoring
- Academic mentoring
- Women in FLEET mentoring (15 external and internal female mentors, an increase from two in 2018).

Sultan Albarakati (RMIT) and Oleh Klochan (UNSW)

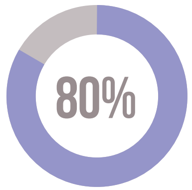
More at FLEET.org.au/mentoring

FLEET MENTORS
TARGET **40**
ACTUAL **40**

FLEET MENTEES
TARGET **55**
ACTUAL **68**

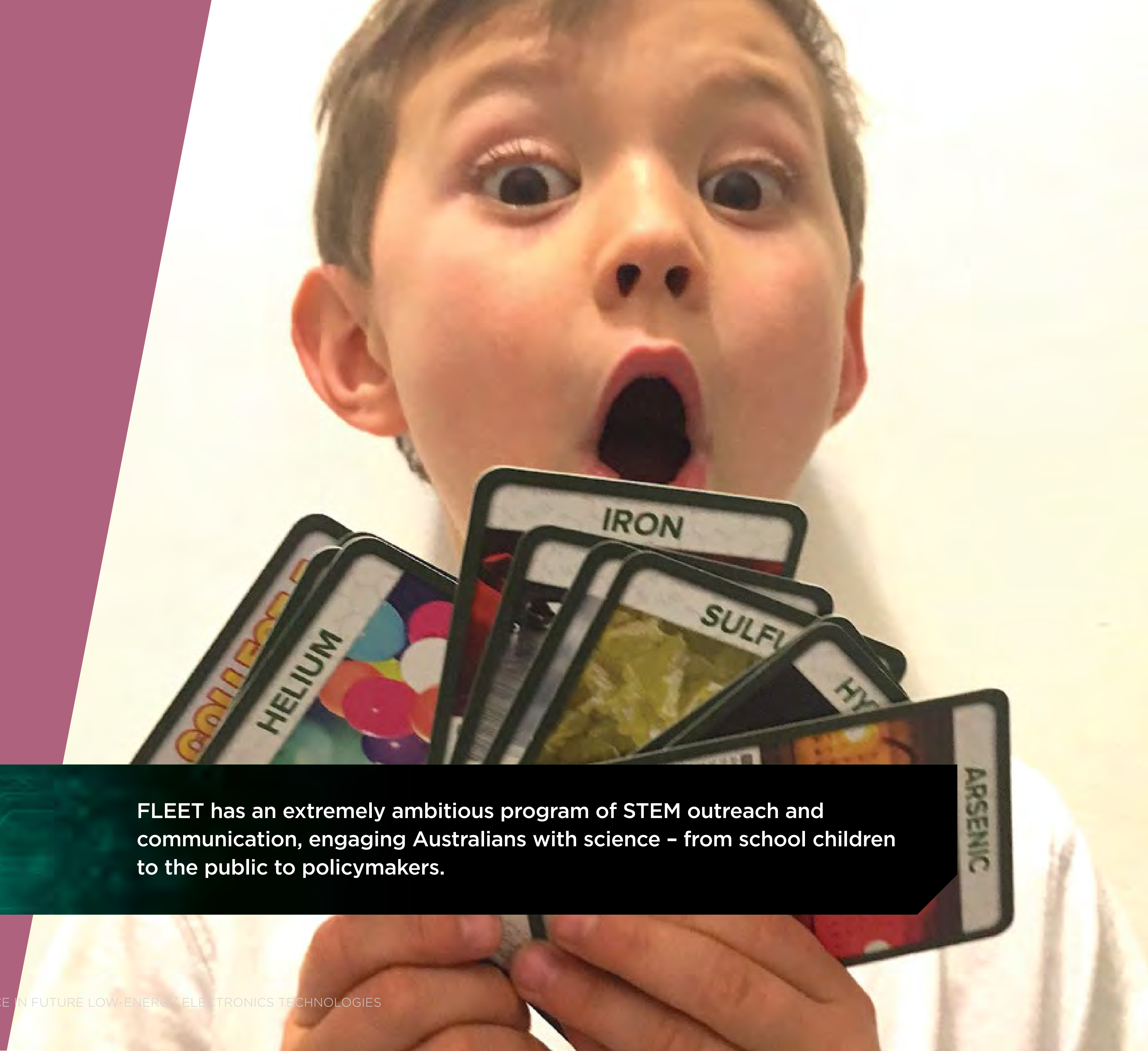


EXTERNAL MENTORS
TARGET **10**
ACTUAL **8**

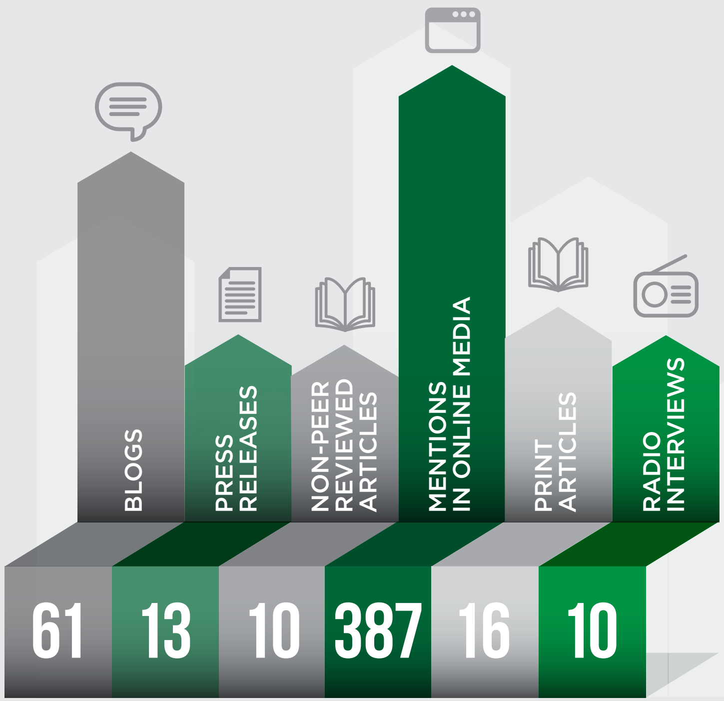


ENGAGE

06



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



899
TWITTER FOLLOWERS
(305 new followers)

596
FACEBOOK FOLLOWERS
(183 new followers)

10,637
VIEWS OF FLEET **YOUTUBE CHANNEL**

5209
AVERAGE MONTHLY **UNIQUE PAGE VIEWS**

2001
AVERAGE MONTHLY NEW USERS **VISIT FLEET.COM.AU**

184
OUTREACH ACTIVITIES INVOLVING FLEET MEMBERS

2022
HOURS SPENT ON **OUTREACH**

12,121
PUBLIC AUDIENCE REACHED THROUGH **OUTREACH ACTIVITIES**

47
HOME SCIENCE ACTIVITIES DEMONSTRATED

387
SCHOOL TEACHERS ENGAGED

11,248
SCHOOL STUDENTS REACHED THROUGH **OUTREACH ACTIVITIES**

SPREADING A PASSION FOR SCIENCE: OUTREACH

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.

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.

This year, Centre researchers reached a remarkable number of students, over 10,500, via participation in public events such as the nine-day Sydney Science Festival (see case study, p68), lab tours, and university open days.

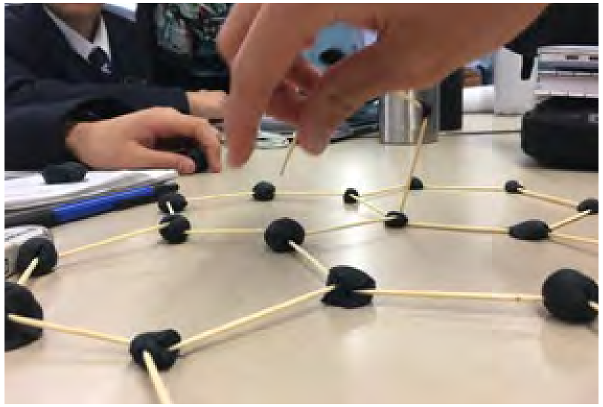
Due to this success, FLEET has voluntarily raised its student outreach target from 200 students in 2019 to 2,000 students from 2020 onwards.

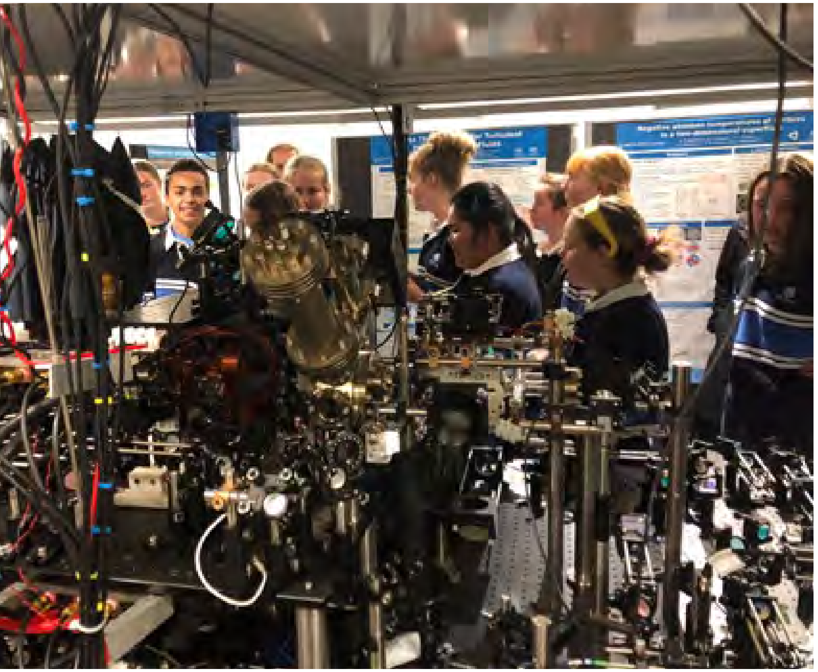
In 2019, FLEET launched a Year 10 'Future electronics' course in partnership with John Monash Science School, Victoria. As well as covering the history of semiconductors and computing, and introducing students to Moore's Law, the course represented Australia's first introduction to superfluids and topological materials at the secondary school level (see case study, p69).

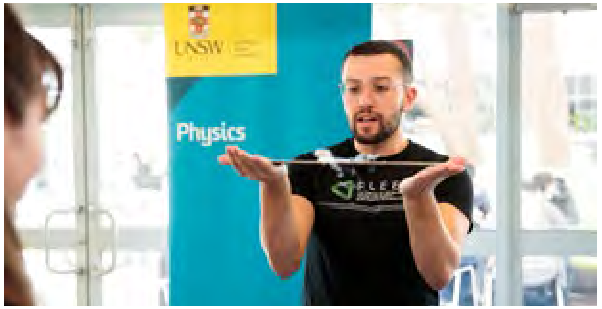
Did you know...

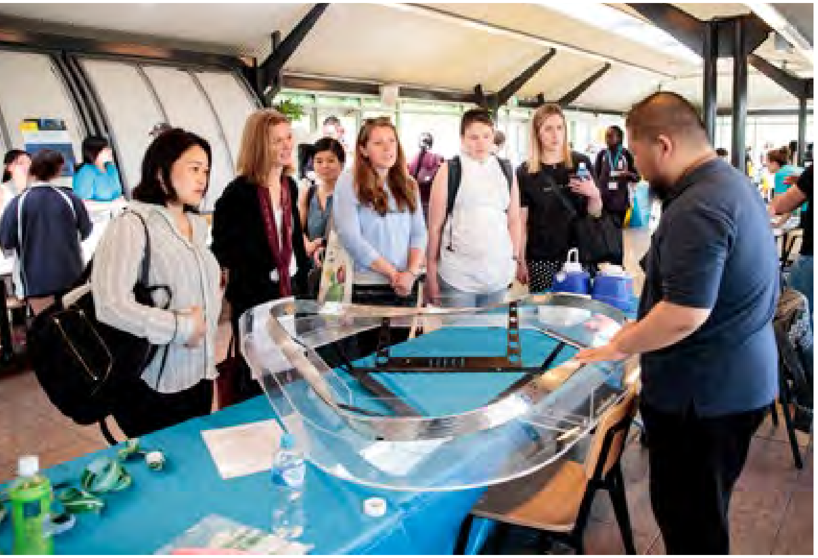
Up to 75% of future jobs will require skills in science, technology, engineering and maths (STEM). Yet school participation in science is in decline.

> 2019 GAVE US great opportunities to combine with other organisations to present our work in a public forum, such as Melbourne Knowledge Week and Sydney Science Festival, allowing us to present to thousands of people that we otherwise would never have seen.
>
> **Dr Dianne Ruka**
> *FLEET Senior Outreach Coordinator*









TECH SCHOOL PARTNERSHIP AND REACHING 10,000 SCHOOLKIDS IN 2019

FLEET's very fruitful partnership with Monash Tech School ramped up in 2019, providing almost-weekly, personal science experiences for secondary students. The Tech School partnership, and key public events, contributed to FLEET blitzing its ambitious school engagement goals in 2019, reaching over 10,500 school kids.

See more, including FLEET's continuing Home Science program, at FLEET.org.au/outreach

CASE STUDY

ENGAGING WITH THE PUBLIC: SYDNEY SCIENCE FESTIVAL

There's nothing like a strong dosage of public outreach to energise scientists. One 2019 event in particular was an outreach 'grand slam' for participating FLEET members.

The Sydney Science Festival was also FLEET's most successful engagement event to date, reaching over 9000 school students in nine days.

FLEET invests significant resources into science outreach, aimed to inspire stronger engagement with science across all levels of the community, from primary and secondary school students to the broader population. This is the reason for the Centre's very ambitious annual goal of 20 outreach hours per member.

Beyond this, science outreach also builds valuable skills for our FLEET members.

Over nine busy days at the Sydney Science Festival, a dozen UNSW FLEET members (including physicists, materials engineers, and chemical engineers) demonstrated the Centre's Mobius strip magnetic track and levitating superconductor for only the second time outside of FLEET nodes.

The 9000+ visiting students ranged from preschoolers to secondary school students.

Regardless of the age group of attendees, those watching were often shocked at first by the initial levitation of the superconductor, followed by surprise as it whizzed around the Mobius strip. People were fascinated to discover how this phenomenon occurred, hopefully inspiring some future scientists.

FLEET's Mobius superconductor track featured at Sydney Science Festival, four university open days, Melbourne Knowledge Week and (on loan) with the ARC Centre for Quantum Computing

Participating FLEET members also found it an energising experience:

> IT WAS great to see school kids so enthusiastic about superconductivity. It's something that has captivated physicists for a century, so being able to share that with a new generation is fantastic.
>
> Dr Sam Bladwell
> *FLEET Research Fellow, UNSW*

> KIDS ARE natural-born scientists. They watched with open-minded curiosity and kept on asking questions.
>
> Dr Aydin Keser
> *FLEET Research Fellow, UNSW*

> WHAT WE liked most about the course (feedback from JMSS students):
> - Logic gates and quantum stuff
> - Practical, hands-on exercises
> - Covering a broad range of areas
> - Cold atoms presenter Carlos Kuhn
> - Learning advanced concepts that no other subject would teach.

CASE STUDY

ENGAGING SENIOR SCHOOL STUDENTS

In 2019, FLEET designed and helped deliver a new, Year 10 'Future electronics' course, in partnership with John Monash Science School, Victoria.

The course covers the history of semiconductors and computing, and introduces the students to Moore's Law. It represents the first time in Australia that secondary school students have been taught about superfluids and topological materials. For most of the 35 students, the course was their first introduction to quantum science.

For FLEET, it was a wonderful opportunity to fine-tune our own explanations of these topics. Fields such as topological materials are relatively new, and the most effective explanations have not yet been agreed upon. We charged the students with helping FLEET improve these explanations, thus involving the students with the challenges of science communication along the way.

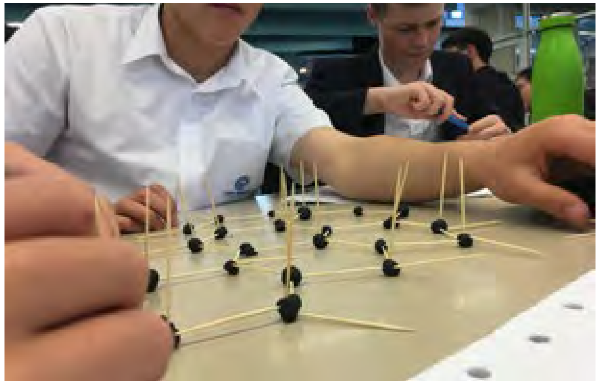
FLEET members helped to develop and deliver the courses, building valuable skills within the Centre, and exposing students to a much more diverse cast of physicists than the thoroughly 'pale, stale and male' 19th-century gentlemen whose names and biographies are traditionally taught in physics classes.

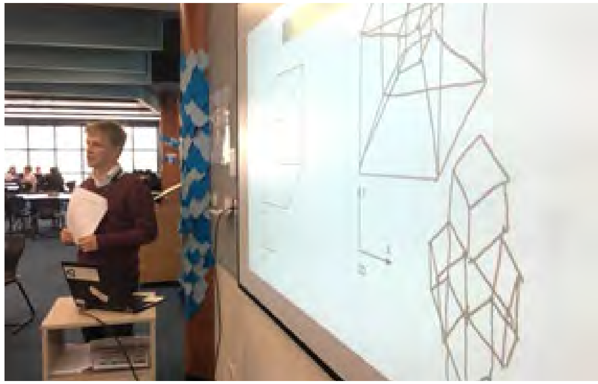
Content covered the spectrum from fundamental atomic and quantum physics to computing and technology, including:

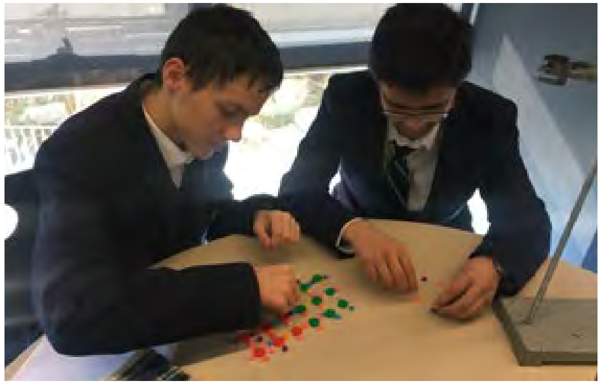
- An atomic understanding of electrical conduction
- Function and construction of transistors, and their use in increasingly complex Boolean logic circuits
- The role of binary numbers in digital computing
- Quantum science, including wave-particle duality and uncertainty and students' hands-on measurements of Young's two-slit experiment
- Superfluids and excitons
- Topology and topological materials
- Ultra-cold atomic physics
- Quantum computing (with the help of the ARC Centre of Excellence for Quantum Computation and Communication Technology, CQC^{2}T)
- Graphene and other two-dimensional (2D) materials.

The course aimed to build a broad, intuitive understanding of the issues among the students, whenever possible, avoiding mathematical derivations and focusing instead on hands-on and discussion exercises that cemented the new knowledge.

The course will be repeated at JMSS in 2020, and FLEET is investigating running the course at other secondary schools.







People reached 28-day avg.
3245

Followers FLEET **Facebook page**
596

Number of people who **Saw our posts**
146,700

Number of times **FLEET videos were watched** at 95%
778

Number of people who **Engaged with our posts**
9824

155
Number of **Posts**

FACEBOOK
@FLEETCentre

1192
Number of **Page visits**

391
Number of **Followers**

Number of **Post views**
43,810

LINKEDIN

SHARING FLEET RESEARCH: COMMUNICATION

FLEET's communications functions include:

- Internal communication to maintain a cohesive Centre
- Informing the Australian public of the benefits being gained from ARC-funded research
- 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 has used 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 (voluntarily increasing the Centre's 'media mentions' target, and exceeding the original goal by a factor of ten).

Number of
Pages per session
1.97

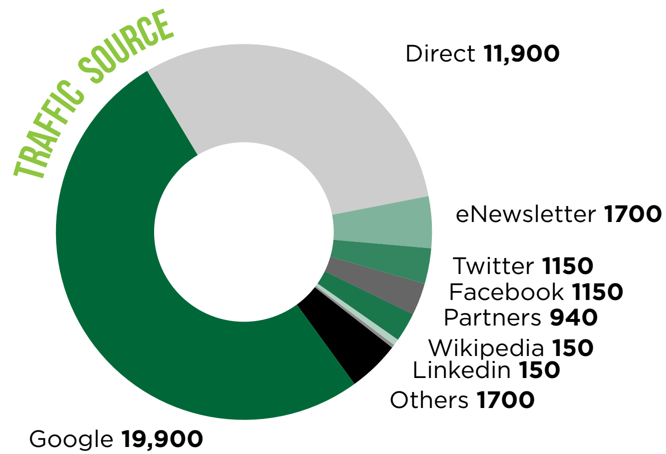
Number
of **New users**
24,150

Number
of **Unique page views**
62,590

Number of
Sessions
38,560

Number
of **Blog posts**
61

WEBSITE
FLEET.org.au



TWITTER
@FLEETCentre

Number of
Profile visits
3770

Number
of **Twitter followers**
899

Number of
Members active
33

Number
of **Tweet impressions**
568,300

672
Number of
Tweets

Number
of **Mentions**
552

Website statistics 2019

1 **20,000**

ENGAGE

CASE STUDY

PERIODIC TABLE CARD GAME

To mark the International Year of the Periodic Table in 2019, FLEET members developed a card game based around 30 elements, taking the opportunity to highlight some of the less-well-known elements that feature in FLEET research, such as bismuth and gallium.

Based on the UK game Top Trumps, the game is accessible to a range of ages. It requires no prior knowledge of chemistry and is designed to build familiarity with elemental properties.

FLEET early-career researchers (ECRs) Dr Daniel Sando and Dr Eli Estrecho took on the challenge of selecting and describing the 30 selected elements, and sourcing engaging, illustrative images.

The game, which has been commercially produced, has been popular among students and public as it has been given away by FLEET members; it has even found a home in Australia's Parliament House (see Science Meets Parliament, right).

CASE STUDY

ENGAGING WITH POLICYMAKERS

Engaging with politicians and other policymakers is key for any Centre of Excellence, and pitching to politicians is a key skill for researchers, whether they are senior or just starting their career in research.

In 2019, three FLEET ECRs were fortunate to attend Science Meets Parliament. Each proved to be remarkably adept at briefing members of the House of Representatives and Senate on the Information and communications technology (ICT) energy issue that underlies FLEET's research mission. And they conscientiously ensured the parliamentarians each received Centre souvenirs, brochures, and invitations to visit!

FLEET's three parliamentary visitors this year were Hareem Khan (RMIT), Oliver Stockdale (University of Queensland) and Dr Semonti Bhattacharyya (Monash University).

Semonti Bhattacharyya with MP Steve Dimopoulos

More at FLEET.org.au/SMP2019

ENGAGE

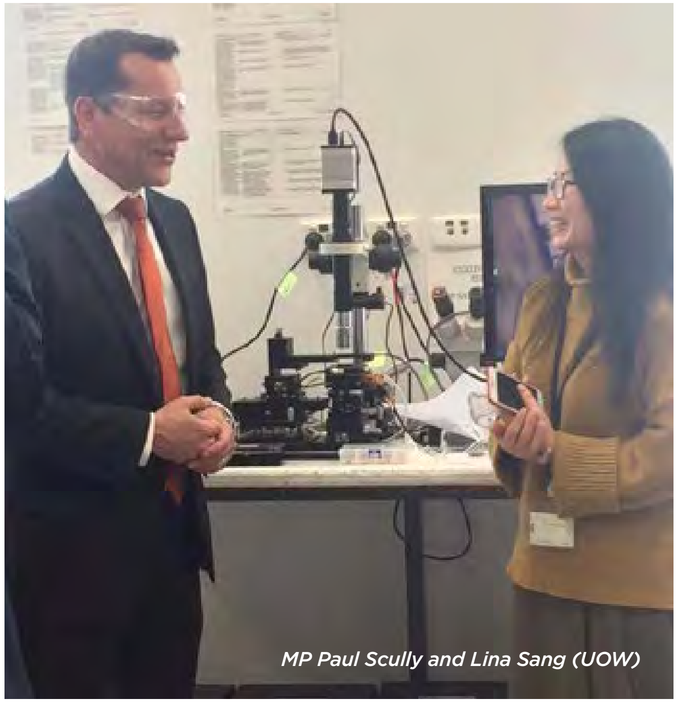
ALSO IN 2019:

- FLEET Director Prof Michael Fuhrer met with Victorian Energy ministry
- A delegation led by Deputy Director Prof Alex Hamilton met NSW Energy ministry officials
- Prof Fuhrer met Victorian Dept of Jobs, Precincts & Regions
- Prof Xiaolin Wang (University of Wollongong) hosted a lab tour by NSW MP Paul Scully
- Prof Fuhrer met with Victorian MP Steve Dimopoulos
- Prof Kourosh Kalantar-zadeh met with Australian Chief Scientist Dr Alan Finkel.

Dimi Culcer (UNSW), Xiaolin Wang (UOW) and MP Paul Scully

Engaging with policymakers

Matt Davis (UQ) school visit with MP Shayne Neumann



MP Paul Scully and Lina Sang (UOW)

COMMUNICATION

RESEARCH BLOG

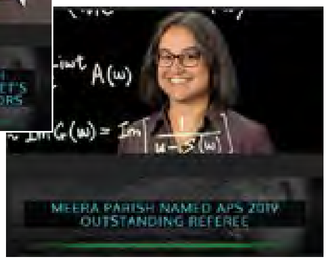
FLEET puts significant effort into web-based blog posts, sharing research news across the Centre, along with outreach, training, equity and other news.

The content from FLEET's research blog feeds into the Centre's social media feed, providing compelling content for followers on Twitter, Facebook and Linkedin.

Blog links in the Centre's monthly newsletter provide broad news to members, affiliates and stakeholders.

FLEET's blog forms an extremely effective channel:

- promoting members' research
- celebrating members' achievements
- highlighting Centre engagement with partners and the wider community.



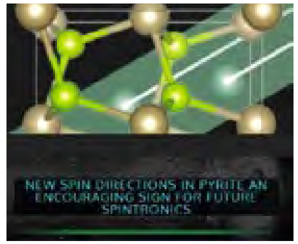
LEGEND

- Research theme 1, topological materials
- Research theme 2, exciton superfluids
- Research theme 3, light-transformed materials
- Enabling technology A, atomically-thin materials
- Enabling technology B, nano-device fabrication

DATE	RESEARCH BLOG POST TITLE	THEME
1 Jan 19	*Learning to tell their science story: ECR comms training*	
1 Jan 19	*Live-streamed FLEET seminars*	
4 Jan 19	*Monash engineers unlock avenue for early cancer diagnosis*	Enabling technology A
22 Jan 19	*Expanded partnership with Tsinghua University: meet two new Partner Investigators*	Research theme 1, Enabling technology A
31 Jan 19	*Pitch perfect: 2018 Idea Factory*	
1 Feb 19	*Networking and skills development: Canberra Summer School*	Research theme 1
21 Feb 19	*Topological defects could be key to future nano-electronics*	Research theme 1
27 Feb 19	*Climate rewind: Scientists turn carbon dioxide back into coal*	
28 Feb 19	*Meera Parish named APS 2019 Outstanding Referee*	Research theme 2, Research theme 3
1 Mar 19	*Three young FLEET scientists off to Lindau Nobel meeting*	
1 Mar 19	*Women in FLEET Fellowships*	
11 Mar 19	*I can't believe it's not graphene: nanoengineering artificial graphene*	Research theme 1
27 Mar 19	*FLEET collaboration reviews ferromagnetism in 2D materials*	Enabling technology A
28 Mar 19	*Read FLEET's latest annual report*	
1 Apr 19	*Welcome new FLEET crew members*	

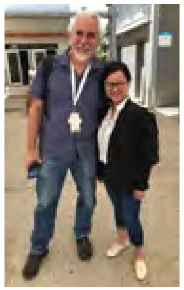
DATE	RESEARCH BLOG POST TITLE	THEME
2 Apr 19	*Excellence in Research in Australia: ERA results*	
13 Apr 19	*Topological physics finds FameLab success*	Research theme 1
13 Apr 19	*Welcoming two new Associate Investigators*	Research theme 2
8 May 19	*New Josephson junction study links quantum theory to experiment*	Research theme 1
26 May 19	*Deciphering fundamental physics of ferroelectricity at the nanoscale*	Research theme 1, Research theme 2, Enabling technology A
27 May 19	*Ultra-cold lithium atoms shed light on pair formation in superfluids, helping identify best theories*	Research theme 3
28 May 19	*Flying the future-computing flag at Melbourne Knowledge Week*	
3 Jun 19	*Tuning the topological insulator Sb_2Te_3: just add iron*	Enabling technology A
12 Jun 19	*Using disorder to build new materials for low-energy electronics: welcome new FLEET AI Julie Karel*	Enabling technology B, Research theme 1
24 Jun 19	*CoEs partner up for pitch training and physics on-stage*	
28 Jun 19	*Order from chaos: Australian vortex studies first proof of decades-old theory*	Research theme 3
3 Jul 19	*Meet molybdenum, an acid-free route to future hydrogen power?*	Enabling technology A, Enabling technology B

DATE	RESEARCH BLOG POST TITLE	THEME
6 Jul 19	*First observation of native ferroelectric metal*	
6 Jul 19	*Collaboration unlocks new magnetic properties for future, faster, low-energy spintronics*	
8 Jul 19	*Welcome Francesca Iacopi, new Associate Investigator*	
16 Jul 19	*Three new research fellows join FLEET*	
17 Jul 19	*Kirrily Rule Partner Investigator*	
17 Jul 19	*Women in FLEET Fellowships*	
26 Jul 19	*Congratulations: Dianne Ruka, exceptional service award*	
30 Jul 19	*Lights out: Putting the ambient air oxidation of Monolayer WS_2 to bed*	
30 Jul 19	*AI Yuerui Lu recognised by Heart Foundation*	
31 Jul 19	*Experimental observation of a new class of materials: excitonic insulators*	
8 Aug 19	*Lindau report (written by RF Eliezer Estrecho, PhD Hareem Khan, RF Matt Reeves)*	
11 Sep 19	*Impossibly cool: Negative absolute temperatures*	
16 Sep 19	*Introducing future electronics at secondary-school level*	
17 Sep 19	*FLEET/UNSW scientists sharing their passion for science: Science outreach in August (written by node administrator Cecilia Bloise)*	
17 Sep 19	*Gutsy effort to produce comprehensive study of intestinal gases*	
20 Sep 19	*Recognition of hard work, PhD submitted – congratulations Stuart Burns, UNSW*	
20 Sep 19	*New Trans-Tasman research will aid search for sustainable future computing: FLEET-MacDiarmid partnership*	
24 Sep 19	*UNSW student focuses kilometre-long laser (written by PhD student Oliver Paull)*	
10 Oct 19	*Controlling the charge state of organic molecule quantum dots in a 2D nanoarray*	
13 Oct 19	*Liquid metals secret ingredients to clean up environment*	
28 Oct 19	*Welcome Mingliang Tian (CAS): new FLEET PI*	
9 Nov 19	*Future electronics and theoretical physics: Sam Bladwell interviewed*	
12 Nov 19	*New spin directions in pyrite an encouraging sign for future spintronics*	
20 Nov 19	*Clarivate highly-cited researchers*	
24 Nov 19	*Discussing future science with future scientists (Queensland)*	
26 Nov 19	*Developing future scientific leaders*	
5 Dec 19	*Gordon Godfrey Workshop advances Australian quantum physics*	
5 Dec 19	*Discovery Projects $2.6m funding boosts FLEET research*	
12 Dec 19	*New Chairs announced*	
12 Dec 19	*Kourosh recognised*	
17 Dec 19	*Mind the gap: FLEET team from Wollongong, Monash reveal a wide-band gap topological insulator (written by AI David Cortie)*	
19 Dec 19	*Quantum tornado on a silicon chip*	
19 Dec 19	*Three of FLEET's future science leaders engaging with policy-makers*	
22 Dec 19	*Building a cohesive Centre: 2019 annual workshop*	



ENGAGE

ANNUAL WORKSHOP IMAGES



CASE STUDY

ENGAGING WITH INDUSTRY

Working towards the overarching goal of creating pathways to translations of research outcomes, FLEET is building links with partners interested in novel electronic devices and systems. Progress towards this important goal in 2019 includes:

- Working to include topological transistors in the Institute of Electrical and Electronics Engineers' (IEEE) International Roadmap for Devices and Systems
- Lodging two provisional patents
- Collaborating on projects with Lockheed Martin, initiated by FLEET's partner network
- Establishing preliminary links with major semiconductor foundry Taiwan Semiconductor Manufacturing Company (TSMC) to develop future collaborative projects
- Linking with the Monash Energy Institute to co-organise industry-engagement events.

In 2020, FLEET will focus on strengthening existing industry relationships and developing new links by:

- Tailoring the Centre's message to industry – developing an information pack containing key capabilities FLEET can offer
- Identifying and pursuing opportunities to reach industry.

In addition, FLEET will hold a training workshop to increase members' awareness of the industry engagement process, including:

- Showcasing success stories from academic research to spin-offs – demonstrating the commercial value of research outcomes
- Explaining the academia-industry partnership development process – with point of views from both industry and academia
- Illustrating university commercialisation processes at FLEET nodes
- Accessing industry grant opportunities.

See the Industry Relations Committee (p90) and new partnerships (p46).

The hidden energy cost of ICT: FLEET's Dr Tich-Lam Nguyen, Monash Energy Conference

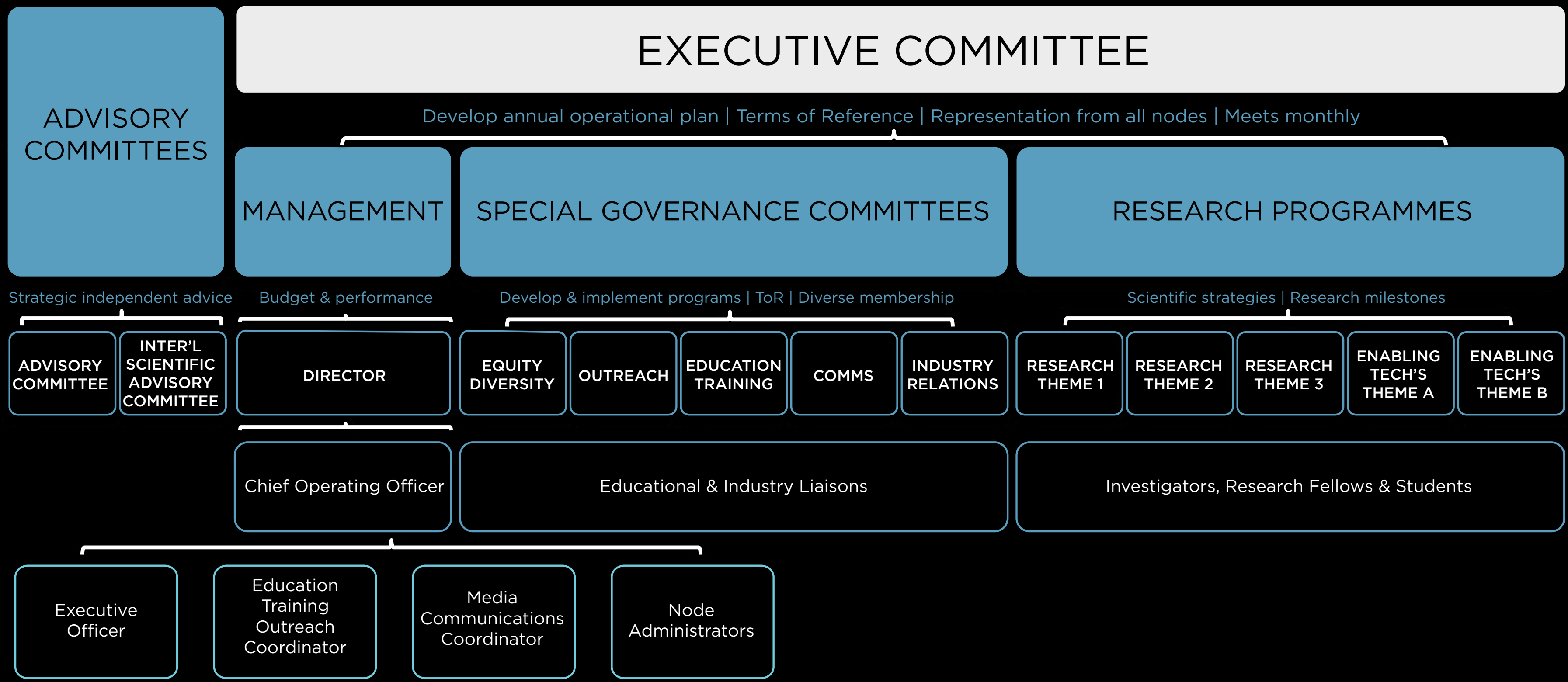
Translation from lab to industry: FLEET Advisor Luigi Colombo speaks at the Centre's annual workshop

INSIDE FLEET

FLEET Annual Workshop 2019

07

FLEET creates a work environment that develops its people, but also values the contribution of members


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

ADVISORY COMMITTEE

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

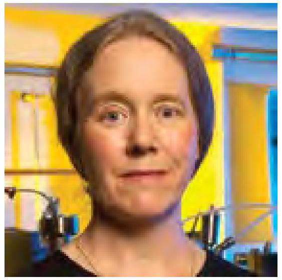
- Reviews FLEET's Annual Operating Plan
- Provides recommendations on financial management
- Provides recommendations on general management and operation, to ensure the Centre achieves its objectives
- Produces an annual report of strengths, weaknesses and opportunities.

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 IAN SMITH
Vice-Provost of Research and Research Infrastructure
Monash University, Australia

PROF LUIGI COLOMBO
Fellow
Texas Instruments, USA

FLEET ADVISORY COMMITTEE REPORT

The FLEET Advisory Committee (AC) congratulates the FLEET team on its strong performance in 2019.

The Centre is having a significant impact in dissipationless electronics with breakthrough results reported in high-impact factor journals for topological structures. Similarly, impressive results were noted in each research theme and enabling technology stream.

A feature of the Centre has been quality over quantity. This is realised in the Centre's publications with two-thirds of all Centre publications for the year being in high-impact-factor journals. It is also realised in the other programs of the Centre, with a well-received mentorship program and with feedback on the Centre's approach to equity and inclusiveness being uniformly positive.

The AC supports FLEET in continuing to focus on gender equity and diversity initiatives. While the field has a low participation rate for women (less than 15% according to Engineers Australia and the Australian Institute of Physics), FLEET has a real opportunity to take its current proportion of female Early Career Researchers from its current level.

The AC agrees with FLEET management that engagement with industry remains an ongoing challenge and encourages increased efforts to engage linkages from the International Scientific Advisory Committee and with networkers working domestically.

In promotion of public science literacy, the number of public and students reached, media mentions and social-media engagement is evidence of the interest engendered by the Centre and the impact its research is having.

The AC recognises and applauds the efforts of FLEET management over the year – the overwhelming impression is of a well-run and enjoyable Centre, a hard combination to manage!

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.

> In FLEET's broad Research theme 1 program to seek dissipationless transition in topological systems there is very good progress, with notable results toward creating the right materials.
>
> In FLEET's Research theme 2, seeking excitonic condensates in atomically-thin TMDs with large binding energy to enable potential room-temperature application, the proposed approaches are certainly feasible and there are theoretical studies supporting them.
>
> In addition the Centre is contributing significantly to training the next generation of leaders in electronic materials, increasing diversity and representation of under-represented groups.
>
> **Prof Ali Yazdani**
> *FLEET ISAC Advisor*

COMMITTEE MEMBERS (TWO-YEAR APPOINTMENT):

PROF WOLFGANG KETTERLE
Professor of Physics
Massachusetts Institute of Technology, USA

PROF ALI YAZDANI
Professor of Physics
Princeton University, USA

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's comprehensive program is designed to develop solutions for future electronics and optoelectronics based on non-silicon components and quantum technologies.
>
> The overall directions are very exciting and FLEET is probably the only consortium at the moment actively investigating quantum solutions for novel electronics. In this sense the very creation of this program is a great achievement by itself.
>
> FLEET also stands out because the Centre's focus is on final functionality, rather than simply materials or devices.
>
> **Sir Kostya Novoselov**
> *FLEET ISAC Advisor*

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.

PROF 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).

DR 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.

> 2019 has been an exciting year for FLEET, making positive impact on improving Centre diversity and creating leadership opportunities for young academics.
>
> **Dr Tich-Lam Nguyen**
> *FLEET Chief Operating Officer*

COMMITTEE MEMBERS

PROF ALEX HAMILTON

Deputy Director

Leader, Research theme 1

Node leader, University of New South Wales

PROF CHRIS VALE

Node leader, Swinburne University

Chair, Outreach Committee

PROF ELENA OSTROVSKAYA

Leader, Research theme 2

Node leader, Australian National University

Chair, Equity and Diversity Committee

PROF KRIS HELMERSON

Leader, Research theme 3

Monash University

> FLEET's FIVE new Committee Chairs, all of whom also join the Centre Executive, will provide an injection of 'new blood' to the Executive, including two Scientific Associate Investigators making this step up to positions of leadership within the Centre.
>
> **Prof Alex Hamilton**
> *FLEET Deputy Director*

PROF KOUROSH KALANTAR-ZADEH

Chair, Industry Relations Committee

University of New South Wales, RMIT University

A/PROF LAN WANG

Leader, Enabling technology B

Node leader, RMIT University

PROF MATTHEW DAVIS

Node leader, University of Queensland

Chair, Education and Training Committee

PROF NAGARAJAN 'NAGY' VALANOOR

Chair, Communications Committee

University of New South Wales

PROF XIAOLIN WANG

Leader, Enabling technology A

Node leader, University of Wollongong

	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 • 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.	**ESTABLISH EFFECTIVE PARTNERSHIPS**	
3.1	Establish international partnerships	Number of: • investigators/ECRs/students visiting partner organisations • visits to FLEET nodes by partners/collaborators
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 full strategic plan see FLEET.org.au/strategic-plan

	GOAL	MEASURE
4.	**FOSTER EQUITY/DIVERSITY IN STEM**	
4.1	Foster a culture of equity and inclusiveness	Response rate to annual surveys High levels of satisfaction with FLEET workplace culture Compliance of all events organised/supported by FLEET with Centre's Equity & Diversity guidelines
4.2	Increase diversity among all cohorts of researchers	Increased number of female researchers/HDR students across FLEET
4.3	Establish career support initiatives for women in FLEET	Increased retention rates of ECR women in 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 public awareness of scientific concepts Increased number of FLEET members participating in STEM Professionals in Schools
5.3	Promote the uptake of STEM subjects in schools	Increased number of girls choosing STEM subjects in senior years at partner schools Increased retention in STEM subjects from year 11 to 12 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	Increased number of external 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
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 govt. agencies & NGOs
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 • student members participating in Three-Minute-Thesis competition, and similar

CECILIA BLOISE

Node Administrator, UNSW

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

KATHLEEN HICKS

Node Administrator ANU

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

CHARLES WELCOME

Node Administrator RMIT

Filling in for Nicci Coad who is on maternity leave, Charles 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.

NICCI COAD

Node Administrator RMIT

On maternity leave

DR 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.

TATIANA TCHERNOVA

Node Administrator Swinburne

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

DR 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.

DR TICH-LAM NGUYEN

Chief Operating Officer

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

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.

> THE FLEET Business Team supports our researchers to achieve the priorities of the FLEET Strategic Plan through training, workshops, communications, education and outreach.
>
> **Dr Charlotte Hurry**
> *FLEET Executive Officer*

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 p50).

PROF ELENA OSTROVSKAYA
Committee Chair, ANU

DR BABAR SHABBIR
Research Fellow, Monash

DR CHARLOTTE HURRY
FLEET Executive Officer

DR DIMI CULCER
UNSW

PROF KRIS HELMERSON
Monash

A/PROF LAN WANG
RMIT

PROF MATTHEW DAVIS
UQ

A/PROF MEERA PARISH
Monash

OLIVER SANDBERG
PhD student, UQ

DR TICH-LAM NGUYEN
FLEET Chief Operating Officer

PROF XIAOLIN WANG
UOW

DR JEFF DAVIS
Incoming Committee Chair, Swinburne

BUILDING FUTURE SCIENCE LEADERS: EDUCATION AND TRAINING COMMITTEE

FLEET is building future Australian science leaders among the Centre's ECRs and HDRs.

FLEET's Education and Training Committee sets the Centre's strategies and sponsorship priorities, checking progress and development requirements (see p56).

DR DIANNE RUKA
Education and Training Coordinator

HAREEM KHAN
PhD student, RMIT

PROF JAN SEIDEL
UNSW

PROF JARED COLE
Incoming Committee Chair, RMIT

PROF MATTHEW DAVIS
Committee Chair, UQ

DR JEFF DAVIS
Swinburne

PROF KRIS HELMERSON
Monash

DR MACIEJ PIECZARKA
Research Fellow, ANU

OLIVER STOCKDALE
PhD student, UQ

PROF XIAOLIN WANG
UOW

> THE CENTRAL organisation of training and development within FLEET encourages a lot of great activities that it wouldn't be possible to do without the Centre.
>
> **Prof Matthew Davis**
> *Chair, Education and Training Committee*

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 p66). FLEET also has a team of educational and outreach associate investigators (see p92).

PROF CHRIS VALE
Committee Chair, Swinburne

DR DIANNE RUKA
Education and Training Coordinator

DR DIMI CULCER
Deputy Chair, UNSW

DR ELIEZER ESTRECHO
Research Fellow, ANU

ERROL HUNT
Communications Coordinator

DR KARINA HUDSON
Research Fellow, UNSW

PROF MATTHEW DAVIS
UQ

A/PROF NIKHIL MEDHEKAR
Monash

WAFA AFZAL
PhD student, UOW

A/PROF MEERA PARISH
Incoming Committee Chair, Monash

> FLEET's outreach program has shown that there's a real passion among people of all ages to learn about and connect with cutting-edge science.
>
> **Prof Chris Vale**
> *Chair, Outreach Committee*

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 p77).

DR JIAN-ZHEN OU
Scientific Associate Investigator, RMIT

MATTHEW GEBERT
PhD student, Monash

MITCHELL CONWAY
PhD student, Swinburne

PROF KOUROSH KALANTAR-ZADEH
Committee Chair, UNSW/RMIT

A/PROF QIAOLIANG BAO
Monash

DR STUART EARL
Research Fellow, Swinburne

DR TICH-LAM NGUYEN
FLEET Chief Operating Officer

PROF XIAOLIN WANG
UOW

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

DR TORBEN DAENEKE
Incoming Committee Chair, RMIT

SHARING FLEET NEWS AND SCIENCE: COMMUNICATIONS COMMITTEE

FLEET's Communications Committee gathers information and leads on stories from diverse nodes, feeding them 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 p70).

PROF NAGARAJAN 'NAGY' VALANOOR

Committee Chair, UNSW

CECILIA BLOISE

Node administrator, UNSW

CHUTIAN WANG

PhD student, Monash

DR DAVID COLAS

Research Fellow, UQ

DR DAVID CORTIE

Incoming Committee Chair, UOW

ERROL HUNT

Communications Coordinator

PROF JARED COLE

RMIT

DR JEFF DAVIS

Swinburne

MATTHIAS WURDACK

PhD student, ANU

STUART EARL

Research Fellow, Swinburne

EDUCATION AND INDUSTRY LIAISONS

FLEET works with specialised educational and outreach liaisons:

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

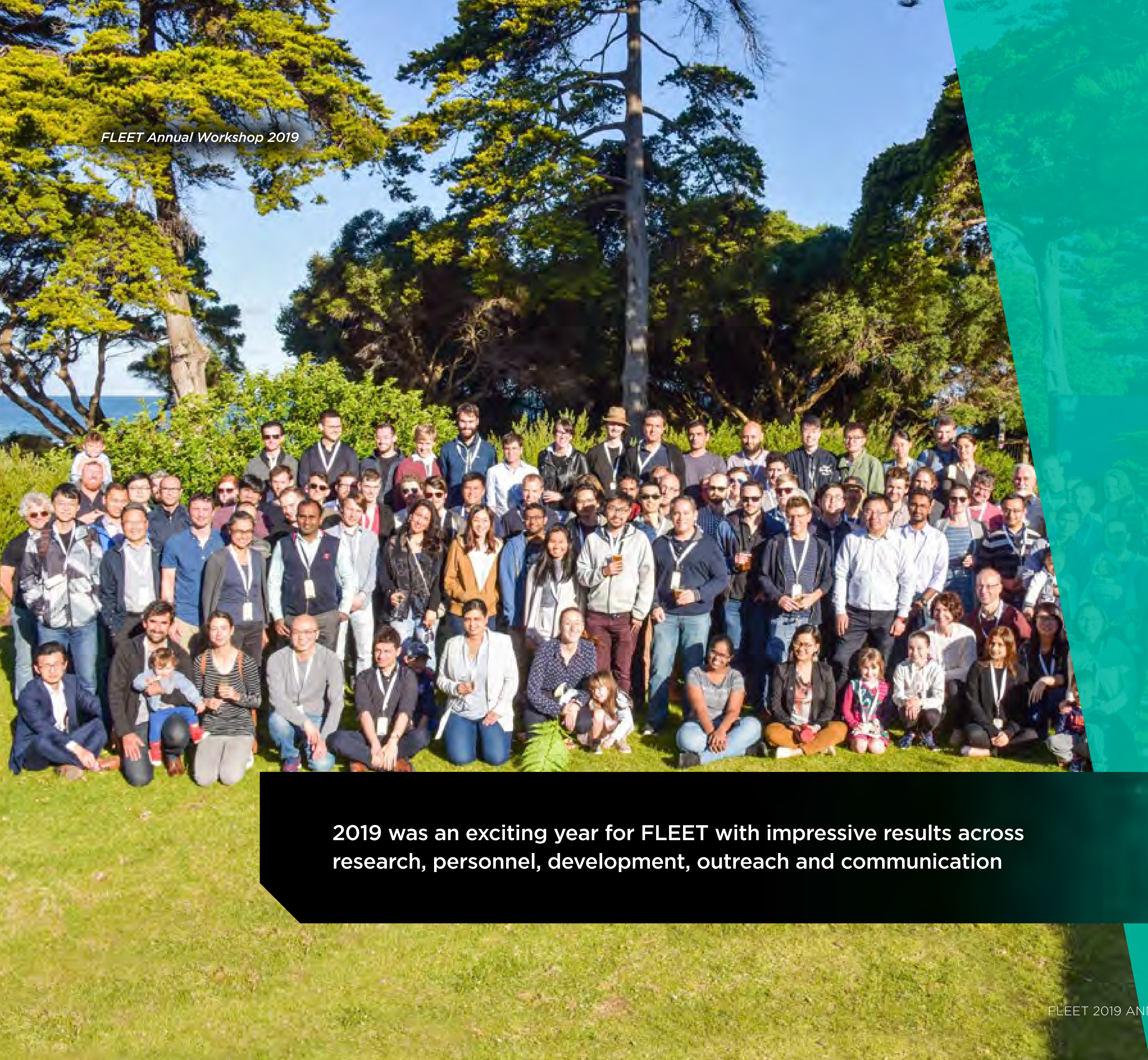
CEO, Imagine Intelligent Materials Pty Ltd

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 Annual Workshop 2019

PERFORMANCE

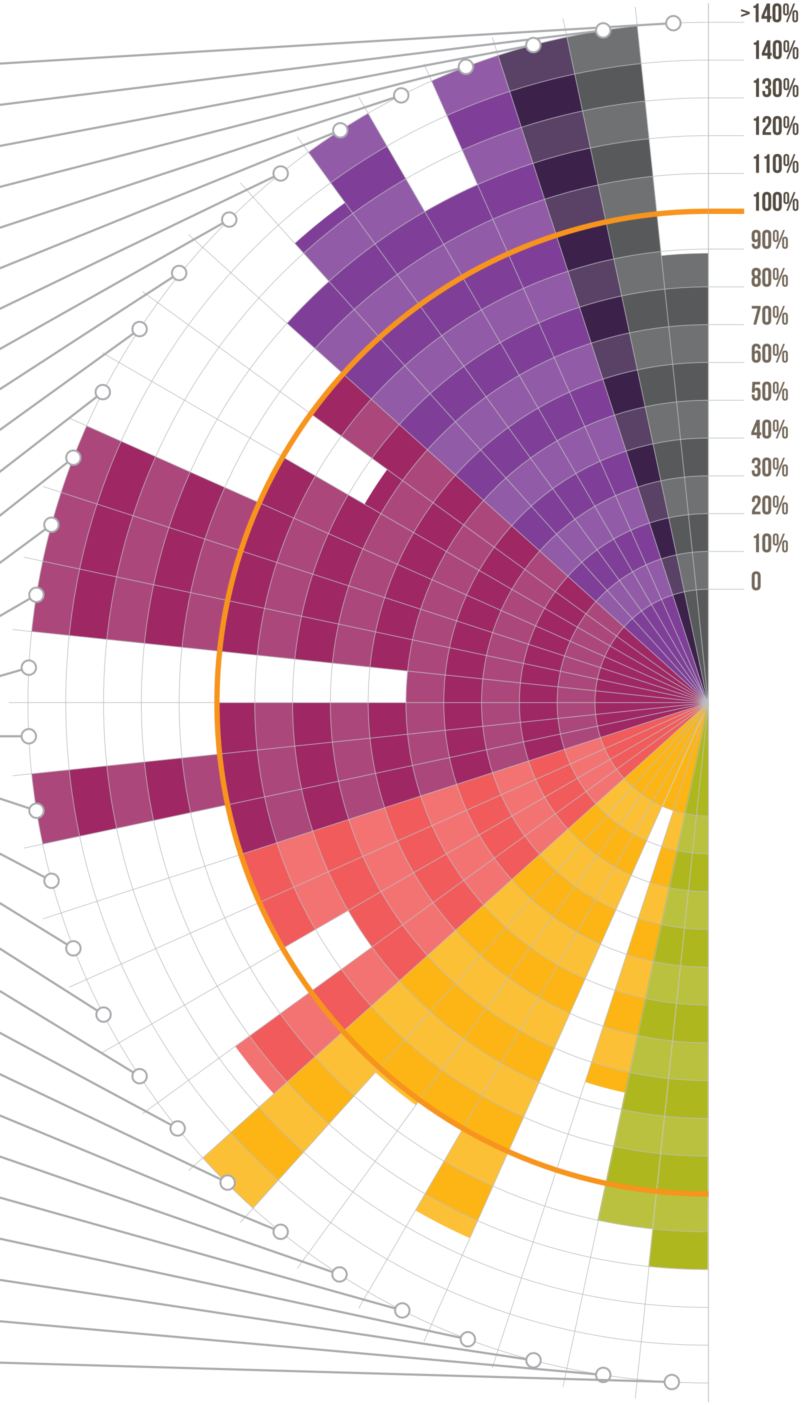
08

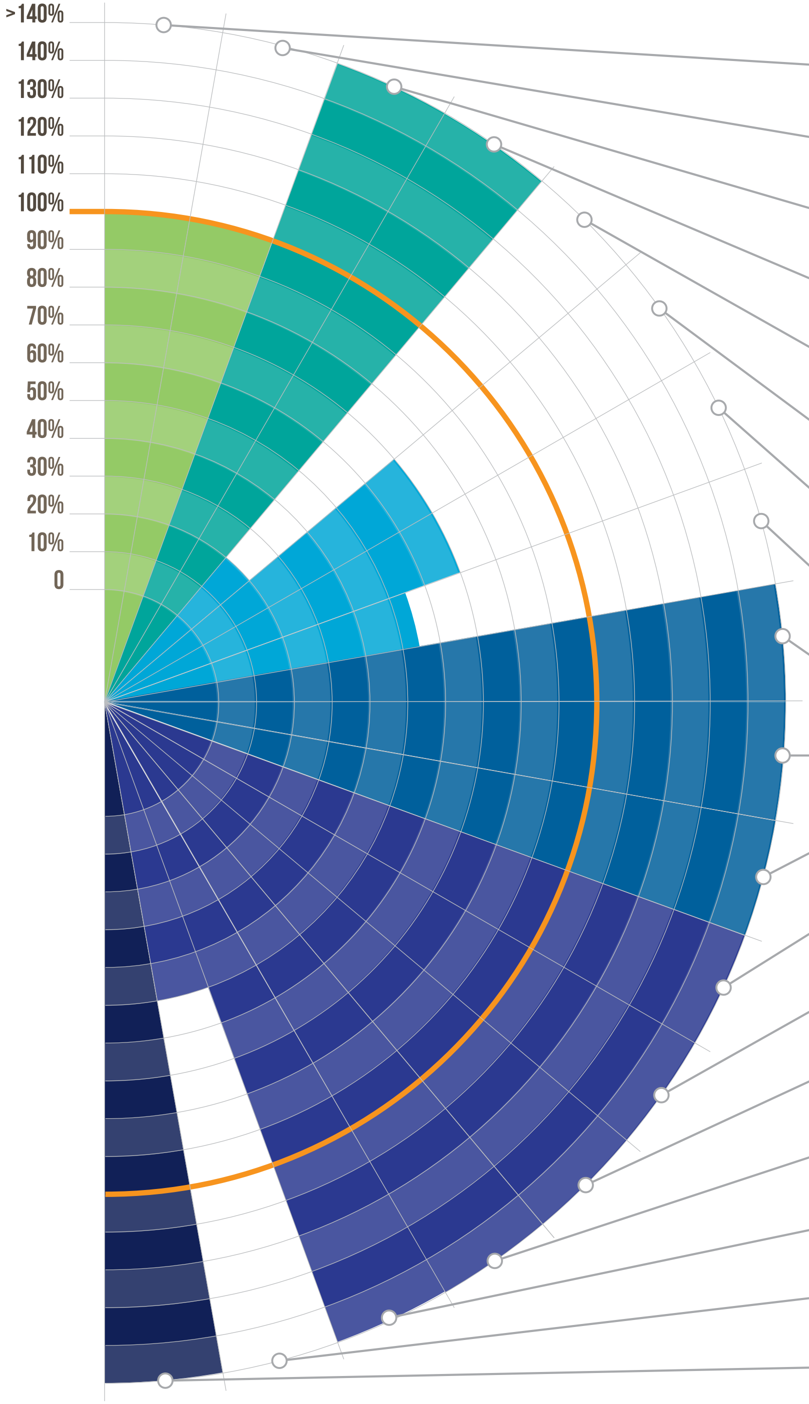
2019 was an exciting year for FLEET with impressive results across research, personnel, development, outreach and communication

PERFORMANCE MEASURES

- Research outputs
- Quality of research outputs
- Personnel
- Education & training
- Mentoring
- Presentations & briefings
- Partnership development

STANDARD KPI	Target	Actual
Journal articles	80	71
Patents applied	1	2
Publications in journals with IF >7	16	44
Postdoctoral researchers FTE	20	36
Honours students	5	6
PhD students	30	53
Associate investigators	27	36
PhD completions	5	6
Research development courses	4	4
Professional development courses	4	3
Training workshops held on diversity and gender equity	1	1
Centre attendees at training workshops	100	742
Non-Centre attendees at training workshops	150	516
Workshops held within Australia	2	4
Workshops held outside Australia	2	1
National symposium and conferences facilitated	1	1
International symposia and conferences facilitated	0	2
Industry engagement workshops held	1	1
Mentoring programs	4	4
Mentors within the Centre	40	40
Mentors external to the Centre	10	8
FLEET mentees	55	68
Technical briefings presented to targeted industry groups	1	4
Presentations to the public	30	31
Presentations to government	4	4
Presentations to industry/business/end-users	4	5
Presentations to non-government organisations	4	0
Presentations to professional organisations and bodies	4	3
Organisational links in training and mentorship programs	10	11
New collaborating organisations	5	6





Actual	Target	CENTRE SPECIFIC KPI
21%	20%	Percentage of women HDRs in FLEET
20%	20%	Percentage of women ECRs in FLEET
96	32	Invited talks at international conferences
5	2	New fellowships awarded to CIs, ECRs and AIs
2	10	International students and ECRs visiting FLEET
21	30	International senior investigators visiting FLEET
7	10	Chief investigators visiting partners
8	15	ECR & HDR students visiting partners
9	5	Non-peer reviewed works by FLEET members
399	250	Mentions of FLEET research in the media
2001	500	New users to Centre website, monthly average
2022	1200	Hours spent in outreach activities
11,248	200	Primary/secondary students reached
387	50	Primary/secondary teachers reached
12,121	2000	Public reached
20	10	Organisational links in education and outreach programs
5	10	End-user relationships established
4601	1500	Additional research income secured by Centre staff ('000)

PERFORMANCE MEASURES

- Gender equity
- Recognition
- Partnership development
- Media
- Outreach
- New funding

PEER-REVIEWED PUBLICATIONS

1. S. Ahmed; X. Ding; P.P. Murmu; N. Bao; R. Liu; J. Kennedy; L. Wang; J. Ding; T. Wu; A. Vinu; J. Yi. *High coercivity and magnetization in WSe_2 by co-doping Co and Nb.* **Small 2019** 1903173 **DOI: 10.1002/smll.201903173** Impact factor >10

2. S. Albarakati; C. Tan; Z.J. Chen; J.G. Partridge; G. Zheng; L. Farrar; E.L.H. Mayes; M.R. Field; C. Lee; Y. Wang; Y. Xiong; M. Tian; F.X. Xiang; A.R. Hamilton; O.A. Tretiakov; D. Culcer; Y.J. Zhao; L. Wang. *Antisymmetric magnetoresistance in van der Waals Fe_3GeTe_2/graphite/Fe_3GeTe_2 trilayer heterostructures trilayer heterostructures.* **Sci. Adv. 2019** 5 7 eaaw0409 **DOI: 10.1126/sciadv.aaw0409** Impact factor >10

3. M.M.Y.A. Alsaif; N. Pillai; S. Kuriakose; S. Walia; A. Jannat; K. Xu; T. Alkathiri; M. Mohiuddin; T. Daeneke; K. Kalantar-zadeh; J.Zhen Ou; A. Zavabeti. *Atomically thin Ga_2S_3 from skin of liquid metals for electrical, optical, and sensing applications.* **ACS Appl. Nano Mater. 2019** 2 7 4665 - 4672 **DOI: 10.1021/acsanm.9b01133** Impact factor 7 to 10 *

4. S. Bladwell; O.P. Sushkov. *Measuring hole g-factor anisotropies using transverse magnetic focusing.* **Phys. Rev. B 2019** 99 8 **DOI: 10.1103/PhysRevB.99.081401** Impact factor less than 4

5. S.R. Burns; D. Sando; B. Xu; B. Dupé; L. Russell; G. Deng; R. Clements; O.H.C. Paull; J. Seidel; L. Bellaiche; V. Nagarajan; C. Ulrich. *Expansion of the spin cycloid in multiferroic $BiFeO_3$ thin films.* **NPJ Quantum Mater. 2019** 4 1 **DOI: 10.1038/s41535-019-0155-2** Impact factor 7 to 10 *

6. C. Carcy; S. Hoinka; M.G. Lingham; P. Dyke; C.C.N. Kuhn; H. Hu; C.J. Vale. *Contact and sum rules in a near-uniform fermi gas at unitarity.* **Phys. Rev. Lett. 2019** 122 20 **DOI: 10.1103/PhysRevLett. 122.203401** Impact factor 7 to 10 *

7. X. Chen; Y. Liang; L. Wan; Z. Xie; C.D. Easton; L. Bourgeois; Z. Wang; Q. Bao; Y. Zhu; S. Tao; H. Wang. *Construction of porous N-doped graphene layer for efficient oxygen reduction reaction.* **Chemical Engineering Science 2019** 194 36 - 44 **DOI: 10.1016/j.ces.2018.04.004** Impact factor less than 4

8. D. Colas; M.J. Davis; F.P. Lauss. *Formation of nonlinear X-waves in condensed matter systems.* **Phys. Rev. B 2019** 99 21 **DOI: 10.1103/PhysRevB.99.214301** Impact factor less than 4

9. D. Cortie; G. Casillas-Garcia; A. Squires; R. Mole; X.L. Wang; Y. Liu; Y.H. Chen; D. Yu. *Spin-wave propagation in alpha-Fe_2O_3 nanorods: the effect of confinement and disorder.* **J. Phys.: Condens. Matter 2019** 31 18 184003 **DOI: 10.1088/1361-648X/ab04ca** Impact factor less than 4 *

10. D. Cortie; G.L. Causer; K.C. Rule; H. Fritzsche; W. Kreuzpaintner; F. Klose. T*wo-dimensional magnets: Forgotten history and recent progress towards spintronic applications.* **Adv. Funct. Mater. 2019** 1901414 **DOI: 10.1002/adfm.201901414** Impact factor >10 *#

11. Z. Dai; Q. Ou; C. Wang; G. Si; B. Shabbir; C. Zheng; Z. Wang; Y. Zhang; Y. Huang; Y. Dong; J.J. Jasieniak; B. Su; Q. Bao. *Capillary-bridge mediated assembly of aligned perovskite quantum dots for high-performance photodetectors.* **J. Mater. Chem. C 2019** 7 20 5954 - 5961 **DOI: 10.1039/C9TC01104H** Impact factor 4 to 7

12. D. Esrafilzadeh; A. Zavabeti; R. Jalili; P. Atkin; J. Choi; B.J. Carey; R. Brkljaca; A.P. O'Mullane; M.D. Dickey; D.L. Officer; D.R. MacFarlane; T. Daeneke; K. Kalantar-zadeh. *Room temperature CO_2 reduction to solid carbon species on liquid metals featuring atomically thin ceria interfaces.* **Nat Commun 2019** 10 1 **DOI: 10.1038/s41467-019-08824-8** Impact factor >10 *

13. Estrecho; T. Gao; N. Bobrovska; D. Comber-Todd; M.D. Fraser; M. Steger; K. West; L.N. Pfeiffer; J. Levinsen; M.M. Parish; T.C.H. Liew; M. Matuszewski; D.W. Snoke; A.G. Truscott; E.A. Ostrovskaya. *Direct measurement of polariton-polariton interaction strength in the Thomas-Fermi regime of exciton-polariton condensation.* **Phys. Rev. B 2019** 100 3 **DOI: 10.1103/PhysRevB.100.035306** Impact factor less than 4 *

14. G. Gauthier; M.T. Reeves; X. Yu; A.S. Bradley; M.A. Baker; T.A. Bell; H. Rubinsztein-Dunlop; M.J. Davis; T.W. Neely. *Giant vortex clusters in a two-dimensional quantum fluid.* **Science 2019** 364 6447 1264 - 1267 **DOI: 10.1126/science.aat5718** Impact factor >10

15. G. Gauthier; S.S. Szigeti; M.T. Reeves; M. Baker; T.A. Bell; H. Rubinsztein-Dunlop; M.J. Davis; T.W. Neely. *Quantitative acoustic models for superfluid circuits.* **Phys. Rev. Lett. 2019** 123 26 **DOI: 10.1103/PhysRevLett. 123.260402** Impact factor 7 to 10

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63. S. Yang; Z. Li; C. Lin; C. Yi; Y. Shi; D. Culcer; Y. Li. *Unconventional temperature dependence of the anomalous Hall effect in $HgCr_2Se_4$.* **Phys. Rev. Lett.** 2019 123 9 **DOI: 10.1103/PhysRevLett.123.096601** Impact factor 7 to 10

64. Y. Yin; M.S. Fuhrer; N. Medhekar. *Selective control of surface spin current in topological pyrite-type OsX_2 (X = Se, Te) crystals.* **NPJ Quantum Mater. 2019** 4 1 **DOI: 10.1038/s41535-019-0186-8** Impact factor 7 to 10

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66. Z. Yue; W. Zhao; D. Cortie; G. Yang; Z. Li; X. Wang. *Modulation of crystal and electronic structures in topological insulators by rare-earth doping.* **ACS Appl. Electron. Mater. 2019** 1 9 1929 - 1936 **DOI: 10.1021/acsaelm.9b00422** Impact factor less than 4 *

67. Z. Yue; X.L. Wang; M. Gu. *Advanced Topological Insulators.* **2019** 45 - 70 **DOI: 10.1002/9781119407317,10.1002/9781119407317.ch2** Impact factor less than 4

68. F.F. Yun; Z. Yu; Y. He; L. Jiang; Z. Wang; H. Gu; X. Wang. *Voltage induced penetration effect in liquid metals at room temperature.* **2019 DOI: 10.1093/nsr/nwz168** Impact factor >10

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73. J. Zheng; C. Luo; B. Shabbir; C. Wang; W. Mao; Y. Zhang; Y. Huang; Y. Dong; J.J. Jasieniak; C. Pan; Q. Bao. *Flexible photodetectors based on reticulated SWNT/perovskite quantum dot heterostructures with ultrahigh durability.* **Nanoscale 2019** 11 16 8020 - 8026 **DOI: 10.1039/C8NR08026G** Impact factor 7 to 10

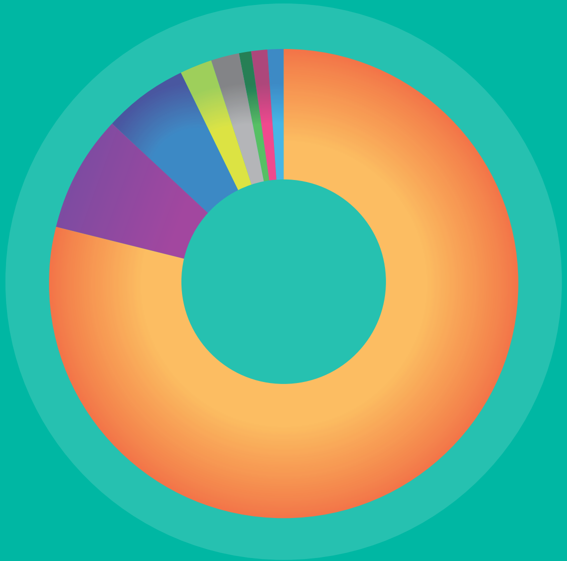
DOI Article Digital object identifier
** publications involving associate investigators*
 # publications involving partner investigators
Impact factor at time of publication

AWARDS, HONOURS AND GRANTS

FLEET MEMBER INVOLVED	TITLE OF FUNDING SCHEME OR AWARD	PROJECT ID	TOTAL AMOUNT OF FUNDING (AUD)	FUNDING SOURCE / AWARDEE
Meera Parish	2019 Outstanding Referee, named by American Physical Society			American Physical Society
Samuel Bladwell	NSW Famelab Australia Finalist			Australia's Science Channel
Semonti Bhattacharyya	VIC FameLab Australia Semifinalist			Australia's Science Channel
Hareem Khan, Eliezer Estrecho, Matt Reeves	Lindau Nobel Laureate Meeting			Australian Academy of Science
Joanne Etheridge	Australian Academy of Science Fellowship			Australian Academy of Science
Xiaolin Wang	Discovery Projects	DP190100150	410,000	Australian Research Council
Zhi Li	Discovery Early Career Researcher Award	DE190100219	359,174	Australian Research Council
Torben Daeneke	Discovery Early Career Researcher Award	DE190100100	400,000	Australian Research Council
Dimi Culcer	Future Fellowship	FT190100062	845,973	Australian Research Council
Qiaoliang Bao, Kourosh Kalantar-zadeh, Yuerui Lu	Linkage Infrastructure, Equipment and Facilities	LE190100116	809,000	Australian Research Council
Lan Wang	Linkage Infrastructure, Equipment and Facilities	LE200100071	535,000	Australian Research Council
Matthew Rendell	CSIRO Alumni scholarship in Physics			CSIRO
Lan Wang, Jared Cole	Lockheed Martin Pty Ltd		Confidential	Industry
Semonti Bhattacharyya	Monash Science Awards			Monash University
Dianne Ruka	Monash Science Awards		5,000	Monash University
Yuerui Lu	Paul Korner Innovation Award		20,000	National Heart Foundation
Yuerui Lu	Future Leader Fellowship		524,000	National Heart Foundation
Dianne Ruka	VESKI Leading the Way – Women in STEM Side-by-Side			State Government
Torben Daeneke	Australia-Germany Joint Research Co-operation Scheme Funding		21,000	Universities Australia
Nagarajan Valanoor	UNSW Research Infrastructure Scheme		110,000	University of New South Wales
Oleh Klochan	UNSW Research Infrastructure Scheme		120,000	University of New South Wales
Daniel Sando	UNSW Research Infrastructure Scheme		293,000	University of New South Wales

2019 INCOME SOURCES, EXPENDITURE CATEGORIES AND CARRY FORWARD

REPORTING PERIOD	2019	2020
CARRY FORWARD FROM 2018	**4,698,933**	
INCOME	**Actual ($)**	**Forecast ($)**
ARC (includes indexation)	4,986,545	4,750,000
Monash University	495,999	496,000
University of New South Wales	404,667	404,667
RMIT University	154,572	154,667
Swinburne University of Technology	116,000	116,000
Australian National University	58,000	58,000
University of Queensland	58,000	57,999
University of Wollongong	58,000	58,000
TOTAL INCOME	**6,331,783**	**6,095,333**
EXPENDITURE	**Actual ($)**	**Commitment ($)**
Personnel		4,969,016
– Salaries	3,547,463	
– PhD scholarships	433,949	
Equipment	428,406	200,342
Maintenance & consumables	765,773	442,966
Travel and visitor support	561,172	574,466
Other		586,265
– Workshops and conferences	159,895	
– Management and administration	139,839	
– Education, outreach and communications	162,969	
– Centre strategic investment	75,034	
TOTAL EXPENDITURE	**6,274,500**	**6,773,055**
CARRY FORWARD TO 2020	**4,756,216**	



** includes indexation*

COLLABORATING ORGANISATION IN-KIND CONTRIBUTIONS

SALARIES 56%
PHD SCHOLARSHIPS 7%
EQUIPMENT 7%
MAINTENANCE AND CONSUMABLES 12%
TRAVEL AND VISITOR SUPPORT 9%
WORKSHOPS AND CONFERENCES 3%
MANAGEMENT AND ADMINISTRATION 2%
EDUCATION, OUTREACH AND COMMUNICATION 3%
CENTRE STRATEGIC INVESTMENT 1%

CONTRIBUTING ORGANISATION	2019 ACTUAL ($)	2020 COMMITMENT ($)
Monash University	1,111,061	709,953
University of New South Wales	563,732	806,140
RMIT University	313,526	354,327
Swinburne University of Technology	425,880	327,507
Australian National University	162,800	69,401
University of Queensland	54,747	164,165
University of Wollongong	152,880	133,135
Australian Nuclear Science and Technology Organisation	419,745	436,000
Australian Synchrotron	242,282	240,465
Beijing Computational Science and Research Center	58,000	63,000
California Institute of Technology, USA	26,800	26,800
China High Magnetic Field Laboratory	14,000	20,000
Columbia University, USA	12,200	36,200
Johannes Gutenberg-Universitat Mainz, Germany	11,200	30,200
Joint Quantum Insitute, USA	104,872	30,000
MacDiarmid Institute - Victoria University of Wellington	15,500	20,000
Max Planck Institute of Quantum Optics, Germany	17,925	34,425
National University of Singapore, Singapore	106,230	99,000
Tsinghua University, China	76,936	118,500
Universitat Wurzburg, Germany	27,512	19,512
University of Camerino	40,758	14,129
University of Colorado Boulder, USA	17,000	17,000
University of Maryland, USA	166,822	62,700
University of Texas, USA	21,000	31,000
Wroclaw University of Science and Technology	31,800	26,800
TOTAL IN-KIND CONTRIBUTIONS	4,195,208	3,890,359

FLEET VISITS TO PARTNER ORGANISATIONS

FLEET TRAVELLER(S)	DATES	INSTITUTION	COUNTRY
Meera Parish	17 January 2019	Tsinghua University	China
Matthias Wurdack	6-18 January 2019	University of Wurtzburg	Germany
Karina Hudson	13 February 2019	MacDiarmid Institute	New Zealand
Lan Wang	14 February 2019	MacDiarmid Institute	New Zealand
Maciej Pieczarka	27 February – 24 March 2019	Wrocław University of Science and Technology	Poland
Michael Fuhrer, James Collins	11-13 March 2019	University of Maryland	United States
Oleg Sushkov	22-17 April 2019	National University of Singapore	Singapore
Maciej Pieczarka	3 May 2019	Wrocław University of Science and Technology	Poland
Alex Hamilton, Feixiang Xiang	13-14 May 2019	National University of Singapore	Australia
Feixiang Xiang, Alex Hamilton	15-18 May 2019	Tsinghua University	China
Michael Fuhrer	26 June 2019	National University of Singapore	Singapore
Oleg Sushkov	12 July 2019	Tsinghua University	China
Lan Wang	2 August 2019	Victoria University of Wellington	New Zealand
Eliezer Estrecho	15 July – 9 August 2019	University of Wurtzburg	Germany
Alex Hamilton	4-6 August 2019	National University of Singapore	Singapore
Elena Ostrovskya	7 September 2019	MacDiarmid Institute - Auckland University	New Zealand
Dimi Culcer	18 September 2019	Tsinghua University	China
Michael Fuhrer	30 September – 3 October 2019	National University of Singapore	Singapore
Oleg Sushkov	6-19 October 2019	Max Planck Institute for Solid State Research	Germany
Feixiang Xiang	15 October 2019	National University of Singapore	Singapore
Dhannesh Gopalakrishnan	17 October 2019	University of Mainz	Germary
Lan Wang	17 November 2019	Chinese Academy of Science – High Magnetic Field Laboratory	China
Maciej Pieczarka	7 November - 24 December 2019	Wrocław University of Science and Technology	Poland
Matthias Wurdack	17-22 December 2019	University of Wurtzburg	Germany

VISITORS TO FLEET NODES

NAME OF VISITOR	INSTITUTION	COUNTRY	POSITION	VISIT DATES	NODES VISITED
Lukas Eng	Dresden Technical University	Germany	Collaborator	28 February 2019	UNSW
Colin Heikes	NIST Center for Neutron Research	United States	Collaborator	19 March 2019	UNSW
Abhikbrata Sarkar	Indian Institute of Technology	India	Undergraduate student	1 May – 30 July 2019	UNSW
Victor Gurarie	University of Colorado Boulder	United States	Partner investigator	28 July – 4 August 2019	Monash
Harley Scammell	Harvard University	United States	Alumnus	27 July – 16 August 2019	UNSW
Ashton Bradley	University of Otago	New Zealand	Collaborator	26-30 August 2019	UQ
Takashi Teranishi	Okayama University	Japan	Collaborator	25 September 2019	UNSW
Shintaro Yasui	Tokyo Institute of Technology	Japan	Collaborator	25 September 2019	UNSW
Laurie Locascio	University of Maryland	United States	Collaborator	28 - 29 September 2019	Monash
Michael Fraser	RIKEN Center for Emergent Matter Science	Japan	Collaborator	9-18 October 2019	ANU
David Neilson	University of Camerino	Belgium	Partner investigator	23 October – 26 December 2019	UNSW
Kurt Gaskill	United States Naval Research Laboratory	United States	Collaborator	25 October – 1 December 2019	Monash
Peter Littlewood	University of Chicago	United States	Collaborator	4-5 November 2019	Monash
Nico Hendrickx	Delft University of Technology	Netherlands	Collaborator	19 November 2019	UNSW
Allan MacDonald	University of Texas	United States	Partner investigator	23 November – 13 December 2019	Monash, UNSW
Claudio Cazorla	UNSW	Australia	Collaborator	26 November 2019	UOW
Bent Weber	Nanyang Technological University	Singapore	Scientific associate investigator	1-8 Decembe 2019	Monash
Shaffique Adam	National University of Singapore	Singapore	Partner investigator	3-10 December 2019	Monash
Zeljko Pastuovic	Australian Nuclear Science and Technology Organisation	Australia	Collaborator	4 December 2019	UOW
Luigi Colombo	Texas Instruments	United States	Advisory Committee member	5-7 December 2019	Monash
Mingliang Tian	High Magnetic Field Laboratory	China	Partner investigator	7-8 December 2019	RMIT
Justin Hodgkiss	MacDiarmid Institute	New Zealand	Partner investigator	7-12 December 2019	Monash

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Scanning tunnelling microscope, Monash

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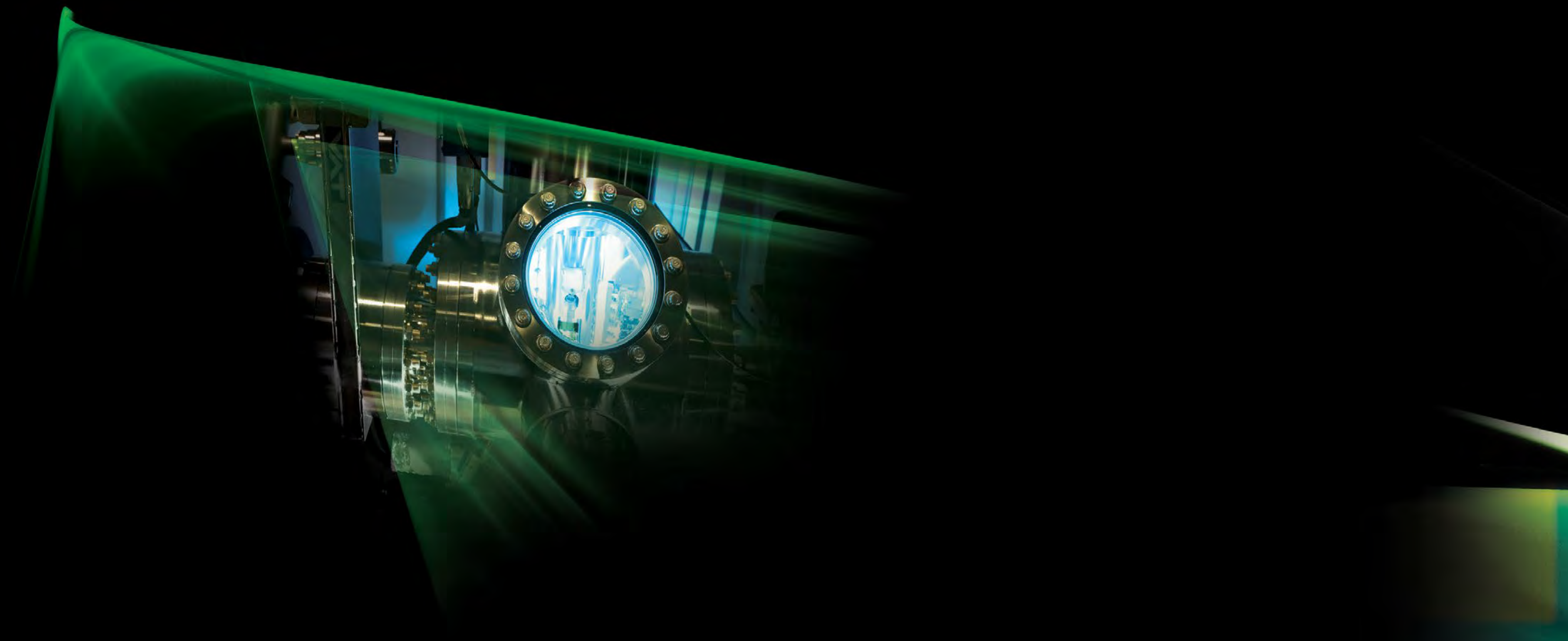

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