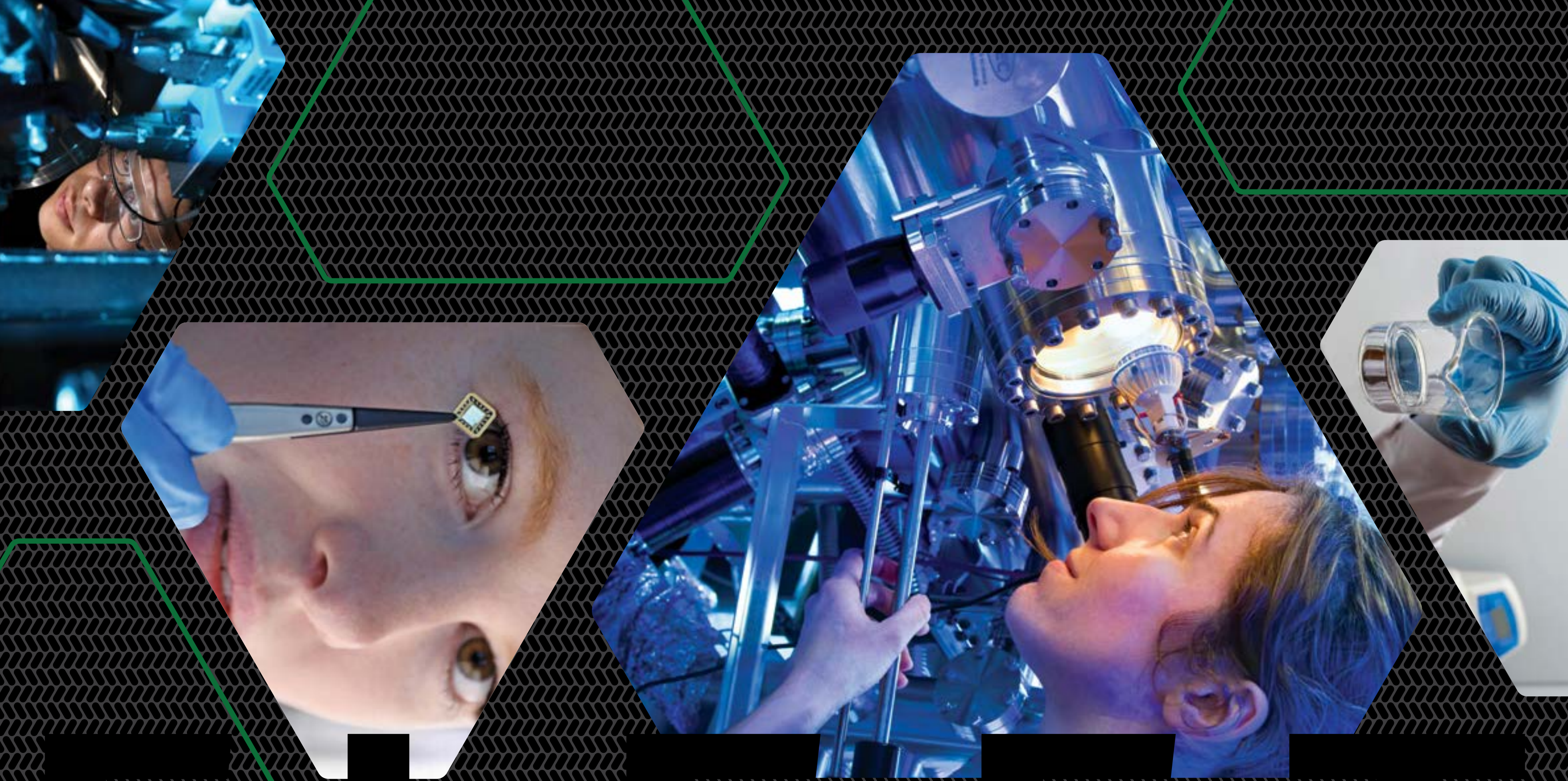


# FLEET 2018

## ANNUAL REPORT

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

*New liquid-metal technique used for a wide range of applications from flexible circuits to filtration devices.*

***Image courtesy of Steve Morton.***

*PhD student Marina Castelli observes topological materials at the atomic-scale using scanning tunnelling microscope.*

***Image courtesy of Steve Morton.***

*Research Fellow Karina Hudson uses nanodevices to study spin-orbit interaction in topological insulators.*

***Image courtesy of Grant Turner.***

*PhD student Fei Hou studies nano-scale properties of functional oxide materials.*

***Image courtesy of Grant Turner.***

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.

# INTRO





# INNOVATE




# COLLABORATE


## EQUITY




## EDUCATION

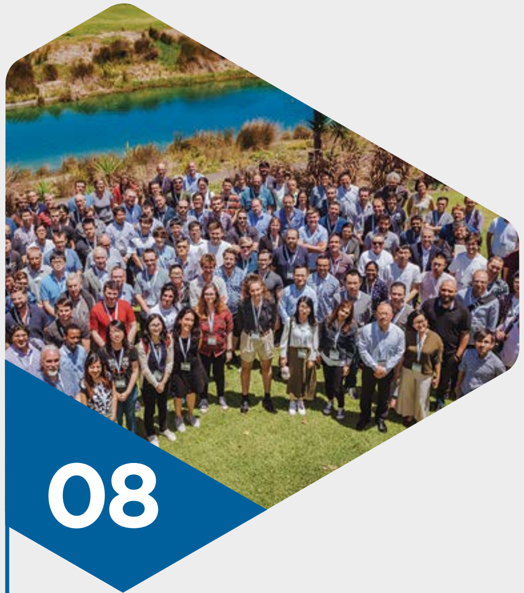



## ENGAGE

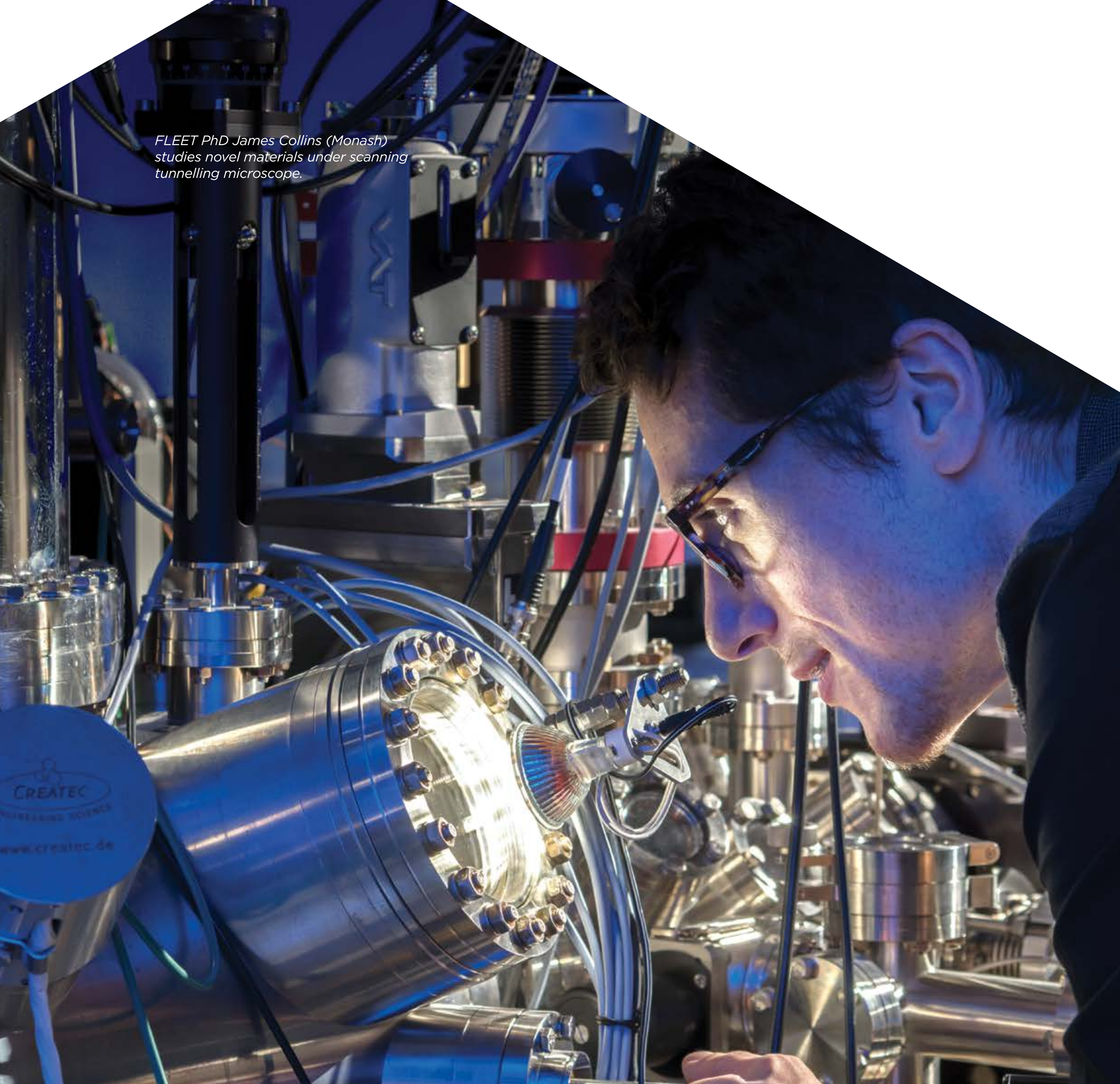



## INSIDE FLEET






## PERFORMANCE




*FLEET PhD James Collins (Monash) studies novel materials under scanning tunnelling microscope.*

# 01 INTRO

FLEET will develop a new generation of ultra-low energy electronics.

## 2017-2023 RESEARCH FUNDING


## IN-KIND COMMITMENT BY COLLABORATING ORGANISATIONS

**$26.2 MILLION**

***FLEET LAUNCHES***
**12 JUNE 2018**

| | |
|---|---|
| 194 | CENTRE MEMBERS AND AFFILIATES |
| 158 | INVESTIGATORS AND RESEARCH ASSOCIATES |
| 49 | EARLY CAREER RESEARCHERS |
| 20 | RESEARCH LEADERS FROM 7 UNIVERSITIES |
| 16 | INTERNATIONAL PARTNER ORGANISATIONS |
| 3 | ADDITIONAL PARTNER ORGANISATIONS IN 2018 |

# RESEARCH MOMENTUM

**2018 marked the first full year of research operations at FLEET, and the Centre's research efforts were well underway by early in the year: most research fellows were on board and key new laboratory capabilities had been installed.**

Although much of the Centre was still in a development phase, FLEET researchers rolled out impressive results that made a splash in the international scientific community, including:

- a new technique to rapidly synthesise a vast array of high-quality metal oxides in two-dimensional (2D) form
- the first demonstration of electrical switching of a topological insulator
- demonstration of a new 2D material platform for intense nano-confined light.

A large part of the mission of a Centre of Excellence is to build capacity in Australia for cutting-edge science where none existed before. It is hard work and cannot happen overnight, but building this capacity provides the foundation for future breakthrough research. The foresight of the Australian Research Council (ARC) and Australian Government in funding Centres of Excellence for seven-year terms gives researchers the time and resources to build new efforts from the ground up.

The timeliness of FLEET's research mission – to reduce the energy used in information and communication technology (ICT) – was reinforced in an important review published in *Nature Electronics*. The article offered evidence that the silicon CMOS industry that supports our current computing technology will soon halt its four decades of exponential technological gains (described by Moore's Law). Instead, as soon as 2020, we could see a steady-state phase marked by the commoditisation of silicon chips. In this new phase, the industry players will compete to make the same chips more cheaply, rather than to make new chips with faster, smaller and more energy-efficient transistors.

> FLEET's sound management team is encouraging scientific productivity in an inclusive way from a diversity of members.
>
> **Professor Andrew Peele**
> Director, Australian Synchrotron
> FLEET Advisory Committee

It remains to be seen whether this change will mark an inflection point in the energy consumption by the ICT sector, but that now seems nearly inevitable. The authors also made a strong case that industry-funded research and development (R&D) will not solve the energy crisis in ICT. They concluded that the sustainable future of the industry is now in the hands of government-funded basic research centres like FLEET.

The foundational science behind FLEET continues to receive important recognition. The 2019 Breakthrough Prize in Fundamental Physics was awarded to Profs Charles Kane and Eugene Mele (University of Pennsylvania). This is well-deserved recognition for their discovery of topological insulators of the type FLEET is now exploiting to make electronic devices.

**FLEET will develop:**

- New systems in which electricity flows with minimal resistance and therefore minimal wasted dissipation of energy
- Devices in which this 'dissipationless' electric current can be switched on and off at will.

These devices will enable revolutionary new electronics and communications technologies with ultra-low energy consumption.

The science underpinning FLEET's work in exciton superfluids also seems close to a breakthrough moment. Researchers in Prof Emmanuel Tutuc's group at the University of Texas, in collaboration with FLEET Partner Investigator Allan MacDonald, in 2018 reported the first hints of an excitonic superfluid in double bilayer graphene, a system first proposed by FLEET Partner Investigator David Neilson and CI Prof Alex Hamilton. More work is needed – and FLEET is rapidly pursuing similar approaches – but the results point to an exciting time ahead in this field.

# 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 up to 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.

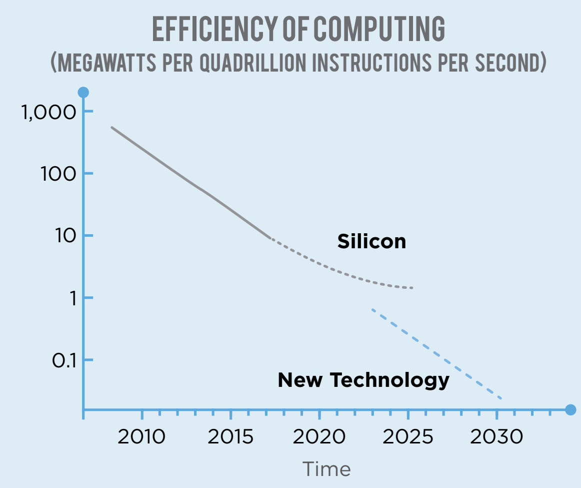
Computers work by activating microscopic switches called transistors – a couple of billion of them are packed into each small computer chip.

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 18 months.

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.

## 2019 FOCUS AREAS

- Focus on research milestones
- Prepare for Centre mid-term review
- Review strategic plan
- Review and renew strategic governance committees
- Review research and Centre operational budgets
- Establish links with industry and end-users
- Communicate FLEET research outputs
- Strengthen links with existing partners
- Develop new strategic collaborations
- Identify opportunities for members for prestigious awards

## DID YOU KNOW...

***Every year, the demand for computation grows by 70%***

## 01 JANUARY

- Hosted International Physics Summer School on Topological Matter in Canberra

## 02 FEBRUARY

- Hosted international ferroelectric materials workshop in Sydney
- Co-hosted FLEET-MacDiarmid collaborative workshop in New Zealand
- PIs Shuyun Zhou and Pu Yu visited Monash, UNSW and UOW

## 03 MARCH

- Published first FLEET Annual Report
- Equity & Diversity event guidelines established

## 04 APRIL

- MP Adam Bandt visted FLEET at RMIT

## 05 MAY

- Senator Simon Birmingham visted FLEET at UOW
- First showcase at Melbourne Knowledge Week
- Centre mentoring programs implemented

## 06 JUNE

- **The FLEET Centre launched**
- Centre Strategic planning workshop in Melbourne
- Co-hosted International Workshop on Topological Structures in Ferroic Materials in Brazil
- Co-hosted ECR training workshop Idea Factory in Queensland

## 07 JULY

- Centre outreach training in Sydney
- PI Victor Gurarie visited Monash and Swinburne

## 08 AUGUST

- First FLEET-wide live-streamed seminar
- AI Shaffique Adam visited Monash and UNSW

## 09 SEPTEMBER

- Centre strategic plan completed
- First Centre equity survey
- Contributed to Australian Academy of Science Women in STEM Decadal Plan

## 10 OCTOBER

- Jared Cole as new Chief Investigator
- YouRforum "Got PhD, What Next?" in Sydney
- Industry engagement showcase with MEMSI in Melbourne
- Co-hosted Conference on Signatures of Topology in Condensed Matter in Italy
- Centre outreach training in Melbourne

## 11 NOVEMBER

- Women in FLEET fellowship recruitment began
- PI David Neilson visted UNSW
- Hosted AIP lab tour at RMIT

## 12 DECEMBER

- FLEET 2018 Annual Workshop
- ECR *Nature* editorial workshop
- FLEET Advisory Meeting
- Hosted International Conference on 2D Materials and Technologies (ICON2D-Mat) in Melbourne
- Hosted 2nd international ferroelectric materials workshop in Sydney
- Advisors Ali Yazdani, Luigi Colombo and AI Shaffique Adam visited UNSW
- Advisor Ali Yazdani and PIs Barbaros Oezylmaz, Victor Galitski, Jim Hone and AI Bent Weber visited Monash
- PI Ian Spielman visited Swinburne

## HIGHLIGHT ACHIEVEMENTS

**FEBRUARY**

Dr Harley Scammell (UNSW) awarded Fulbright Scholarship to work at Harvard University

**APRIL**

A/Prof Qiaoliang Bao (Monash) awarded the Technology Ambassador Fellowship by Australian National Fabrication Facility – Melbourne Centre for Nanofabrication

**JUNE**

Centre Launch **(see p78)**

**AUGUST**

Prof Kourosh Kalantar-zadeh (UNSW/RMIT) named an Australian Research Council (ARC) Laureate Fellow

**OCTOBER**

Prof Jared Cole (RMIT, shown left) promoted to FLEET CI and full professor

Three FLEET ECRs in ten-person team nominated by Australian Academy of Science for the 2019 Lindau Nobel meeting: Hareem Khan (RMIT), Dr Matt Reeves (UQ) and Dr Eli Estrecho (ANU)

**NOVEMBER**

Three members named in Clarivate highly-cited researchers: Prof Michael Fuhrer (Monash), Prof Kourosh Kalantar-zadeh (UNSW/RMIT) and A/Prof Qiaoliang Bao (Monash)

Yonatan Ashlea Alava awarded UNSW School of Physics Research Expo Poster Prize

Ali Zavabeti completed PhD with nine FLEET publications

**DECEMBER**

Honours student Bernard Field won Rodney Turner Prize for Best Honours Thesis in Physics and Astronomy and JJ McNeill Prize for Top Honours Student in Physics (Monash)

# MESSAGE FROM THE DIRECTOR

FLEET grew and strengthened throughout 2018, and now comprises 20 chief investigators, 21 partner investigators, 45 research fellows and more than 70 students.

## CUTTING EDGE CAPABILITIES

FLEET continued to build new experimental capabilities: the toroidal ARPES analyser at the Australian Synchrotron saw its first experimental runs; and van der Waals heterostructures – stacks of atomically-thin materials – were assembled into devices at RMIT and Monash universities.

This development of cutting-edge laboratory capability continues into 2019: a quantum gas microscope capable of imaging individual atoms in cold-atom condensates is being developed at Swinburne; a suite of cryostats for electric and magnetic measurements at ultra-low temperatures and ultra-high magnetic fields is arriving soon at RMIT and Monash; and ultra-fast scanning tunnelling microscopy is being developed at Monash.

## RESEARCH RESULTS

2018 was the first full year of FLEET operations, and the Centre's scientific outputs accelerated, with much to report:

- FLEET's topological materials team (Research theme 1) has made significant strides towards a topological transistor, demonstrating for the first time electric field–controlled switching of a material from topological insulator to conventional insulator. The experiments on atomically-thin layers of $Na_3Bi$ showed very large band gaps (400 meV and 100 meV respectively) in topological and conventional states. This indicates that room-temperature operation may be possible, and brings the major FLEET milestone of achieving topological switching at room temperature closer than originally expected **(see case study p26)**.
- FLEET's exciton superfluid team (Research theme 2) demonstrated a new capability to measure exciton-polariton condensate formation with unprecedented time resolution in a single-shot mode. This work revealed the dynamics of individual condensate events for the first time; previously, individual results were 'hidden' in experiments that averaged many events **(see p32)**.
- The effort to move exciton-polariton condensates to two-dimensional (2D) materials and higher temperatures is proceeding as a combined effort with the nano-device fabrication team, with progress in fabricating microcavities and integrating them with 2D materials.
- The nano-device fabrication team (Enabling technology B) also demonstrated an unprecedented new ability to confine strong and long-lived nanoscale light fields (plasmons) in the atomically-thin material $MoO_3$, offering intriguing new possibilities for light-switched materials.
- FLEET's light-transformed materials theme (Research theme 3), a unique collaboration between theorists and experimentalists working both in condensates of ultra-cold atoms and solid-state 2D materials, is progressing in all fronts: a theoretical understanding of the curious phenomenon of 'negative mass' was developed **(see p38)**; cold-atom condensates confined in 2D were shown to exhibit a quantum anomaly associated with symmetry breaking in the presence of strong interactions **(see p36)**; and FLEET researchers carried out their first experiments to demonstrate engineering the states of electrons in 2D using ultra-fast laser pulses.
- Researchers in the atomically-thin materials theme (Enabling technology A) serendipitously discovered that $In_2Se_3$ harbours room-temperature ferroelectricity, making it only the second-known 2D ferroelectric.
- A process developed by FLEET to make 2D metal oxides on the surface of liquid metals was shown to be useful for making low-cost water filters **(see p42)**.

These types of discoveries show that the benefits of discovery-based research extend beyond the focused objectives of the Centre, and will have important impacts in a diverse range of fields.

## NEW INTERNATIONAL PARTNERSHIPS

Establishing close and synergistic links with international partners is an important ingredient in FLEET's success. FLEET's partnership network expanded significantly in 2018:

- Profs Andrea Perali and David Neilson of the University of Camerino in Italy, long-time collaborators with FLEET Deputy Director Alex Hamilton, add critical expertise on the theory of exciton superfluids.
- FLEET's fruitful relationship with Tsinghua University in Beijing, China, expanded with the Centre welcoming Prof Shuyun Zhou (expert on the electronic structure of novel 2D materials) and Prof Pu Yu (expert on emergent phenomena at 2D interfaces of correlated electron systems).
- Prof Grzegorz Sek of Wroclaw University of Science and Technology in Poland, a specialist in novel epitaxial nanostructures for nanophotonics, opto-electronics and sensing, adds his expertise to the effort in exciton-polariton condensation in FLEET.
- Prof Hai-Qing Lin directs the Beijing Computational Science Research Center (CSRC) in China and connects FLEET to CSRC's large multidisciplinary effort in computational science and condensed matter research.

FLEET continues to explore additional fruitful partnerships: 2018 saw two joint workshops in Australia and New Zealand with the MacDiarmid Institute, New Zealand's premier materials science centre.

## SCIENTIFIC LEADERSHIP

Beyond the scientific achievements, FLEET aims to change the culture of research in science, technology, engineering and mathematics (STEM) fields. While some progress was achieved in 2018, the difficulty of achieving FLEET's goal of at least 30% representation of women across all levels of the Centre was clear.

Of particular concern was the fact that only 20% of research fellows hired were women. The rate was even worse for the many fellows who were appointed directly from existing roles at nodes – only 14% of these were women. This is further evidence of the typical pattern that sees the proportion of women falling at each succeeding career stage.

To boost our representation of women, FLEET has directed strategic funding to advertise two women-only fellowships across the Centre. These new, widely-advertised positions avoid the problem of highly-focused searches, which often find very few respondents. This is the first such initiative for a Centre funded by the Australian Research Council (ARC), and the response has been very high, with almost 70 applicants. Such interest suggests that we are indeed locating talent overlooked in previous, targeted searches.

Elsewhere, FLEET has received overwhelmingly positive feedback for its family-friendly conference policies. Many participants brought families to the Centre's two annual workshops, and the FLEET-organised International Conference on 2D Materials, all of which included free child care for participants. In 2018, FLEET developed an equity policy to apply to all events sponsored by FLEET, which will help spread inclusive policies well beyond the Centre.

FLEET continues to offer excellent training and mentorship opportunities for all its members. In 2018, FLEET organised a YouRforum workshop on career development, was a key participant in the ANU Summer School on Topological Matter, joined with the EQUS Centre (the ARC Centre of Excellence for Engineered Quantum Systems) to run the Idea Factory, and hosted a paper-writing masterclass by *Nature* editor Luke Fleet (no relation!).

> FLEET has made good progress in improving gender balance through enhancing systemic support for women and early career researchers.
>
> **Professor Cathy Foley**
> Chief Scientist, CSIRO
> FLEET Advisory Committee

Also critical to FLEET's mission is bringing an understanding of the challenges addressed by FLEET, and the new science FLEET is using, to students and the public at large.

FLEET's outreach activities in 2018 included more than 1,500 hours of activity by Centre personnel, reaching over 2,000 school students and over 11,000 members of the public.

The FLEET superconducting Mobius strip – demonstrating topology and dissipationless conduction in a mesmerising fashion – is a smash hit with everyone who sees it. It has now been duplicated, with the original going to Scienceworks museum, and new, upgraded versions now captivating audiences in Victoria and New South Wales **(see p76)**.

*FLEET Research Fellow Karina Hudson (UNSW) uses sensitive nanodevices to study spin-orbit interaction in topological insulators.*

# 02 INNOVATE

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

> Topological materials

> Exciton superfluids

> Light-transformed materials

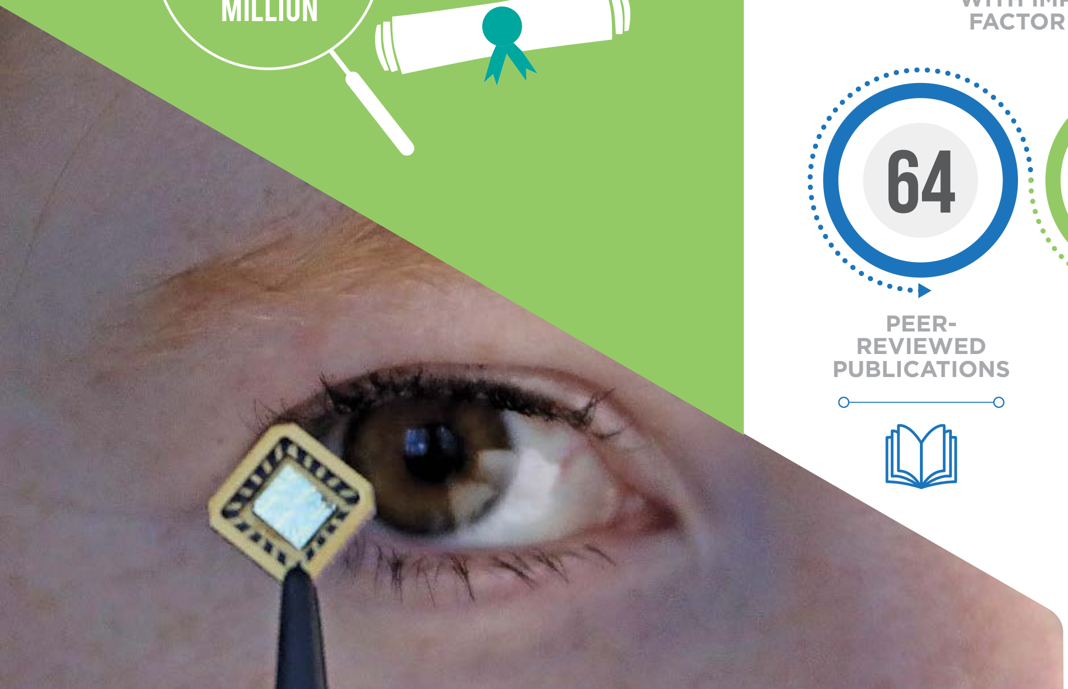
The above approaches are enabled by the following technologies:

> Atomically-thin materials

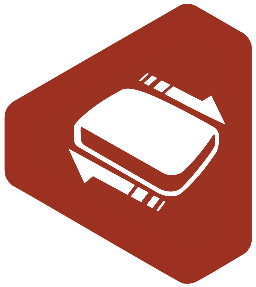
> Nanodevice fabrication

**ADDITIONAL INCOME**
SECURED FOR FLEET


**VALUE IN RESEARCH GRANTS**
AWARDED TO FLEET INVESTIGATORS


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



## RESEARCH THEME 1: TOPOLOGICAL MATERIALS

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

Topological insulators conduct electricity only along their edges, and strictly in one direction, without the '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**

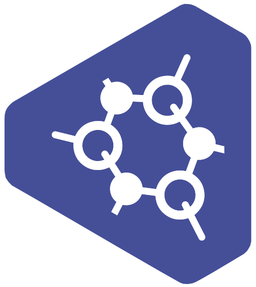
## RESEARCH THEME 3: LIGHT-TRANSFORMED MATERIALS

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 p34**

**These research approaches are enabled by the following technologies:**



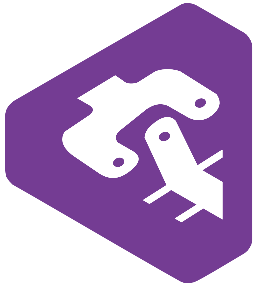
## ENABLING TECHNOLOGY A: ATOMICALLY-THIN MATERIALS

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 p40**



## 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 p46**

# FLEET CHIEF INVESTIGATORS BY THEME

> I am motivated to improve the quality of modern life by developing next-generation, high-performance electronic or optical computing devices.
>
> **A/Prof Qiaoliang Bao**
> FLEET Chief Investigator,
> Monash University

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.

A pioneer of the study of electronic properties of 2D materials, Michael is an ARC Laureate Fellow, 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 2D and nanoscale electronic conduction, and hole behaviour 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.

XIAOLIN WANG

**Node leader, UOW**

Directing Enabling technology A, Xiaolin investigates charge and spin effects in magnetic topological insulators, and leads fabrication 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, Matthew studies transitions between novel non-equilibrium states of matter, focusing on relaxation in non-equilibrium and destructive effects of coupling to the environment.

### 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 for Research themes 1 and 2.

### 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 themes 1 and 2, 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 themes 2 and 3.

### KOUROSH KALANTAR-ZADEH

**UNSW / RMIT**

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

### MEERA PARISH

**Monash**

Meera investigates the robustness of excitonic superfluidity to an electron-hole density imbalance in bilayers in Research theme 2, searching for exotic forms of superfluidity. She also studies impurities dynamically coupled to fermion-pair superfluids in Research theme 3.

### 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

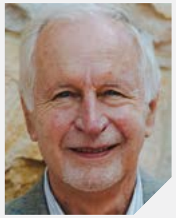
**Allan MacDonald**
University of Texas

**Andrea Perali**
University of Camerino

**Anton Tadich**
Australian Synchrotron

**Antonio Castro Neto**
National University of Singapore

**Barbaros Oezyilmaz**
National University of Singapore



**David Neilson**
University of Camerino

**Ferenc Krausz**
Max Planck Institute of Quantum Optics

**Gil Refael**
California Institute of Technology

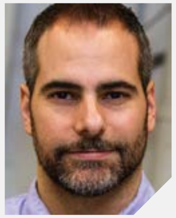
**Grzegorz Sek**
Wroclaw University of Science and Technology

**Hai-Qing Lin**
Beijing Computational Science Research Center

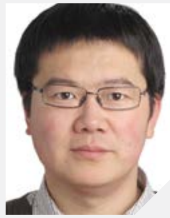
**Ian Spielman**
University of Maryland

**Jairo Sinova**
Mainz University

**James Hone**
Columbia University



**Johnpierre Paglione**
University of Maryland



**Pu Yu**
Tsinghua University

**Qi-Kun Xue**
Tsinghua University

**Shuyun Zhou**
Tsinghua University

**Sven Hoefling**
University of Wurzburg

**Victor Gurarie**
University of Colorado

**Victor Galitski**
University of Maryland

**William Phillips**
University of Maryland

**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

## SCIENTIFIC ASSOCIATE INVESTIGATORS

**Bent Weber**
Nanyang Technological University Singapore

**David Cortie**
University of Wollongong

**Jesper Levinsen**
Monash University

**Jian-zhen Ou**
RMIT University

**Joanne Etheridge**
Monash University

**Mark Edmonds**
Monash University

**Martin Schultze**
Max Planck Institute of Quantum Optics

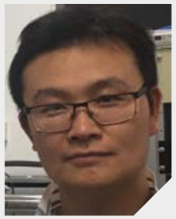
**Nicholas Karpowicz**
Max Planck Institute of Quantum Optics

**Paul Dyke**
Swinburne University

**Shaffique Adam**
National University of Singapore

**Torben Daeneke**
RMIT University

**Yuerui (Larry) Lu**
Australian National University



**Zhi Li**
University of Wollongong

## MASTERS AND HONOURS STUDENTS

**Bernard Field**
Monash University

**Matthew Hendy**
Monash University

**Matthew Gebert**
Monash University

**Mitchell Conway**
Swinburne University

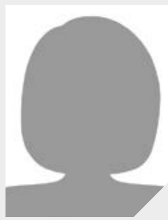
**Oliver Stockdale**
University of Queensland

**Qile Li**
Monash University

**Yik Kheng Lee**
RMIT University

**Zeb Krix**
University of New South Wales

**Zhanning Wang**
University of New South Wales



**Zixin Liang**
MASTERS STUDENT
Australian National University

## RESEARCH FELLOWS

**Ali Zavabeti**
RMIT University

**Aydin Keser**
University of New South Wales

**Babar Shabbir**
Monash University

**Benjamin Carey**
Alumnus, now at University of Munster

**Carlos Claiton Noschang Kuhn**
Swinburne University

**Changxi Zheng**
Monash University

**Cornelius Krull**
Monash University

**Daisy Qingwen Wang**
University of New South Wales

**Daniel Sando**
University of New South Wales

**David Colas**
University of Queensland

**Dmitry Miserev**
Alumnus, now at University of Basel

**Eliezer Estrecho**
Australian National University

**Elizabeth Marcellina**
Alumnus, now at Nanyang Technological University Singapore

**Feixiang Xiang**
University of New South Wales

**Gary Beane**
Monash University

**Golrokh Akhgar**
RMIT University

**Guangyao Li**
Monash University

**Guolin Zheng**
RMIT University

**Harley Scammell**
Alumnus, now at Harvard University

**LEGEND**

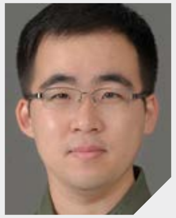
- Research theme 1, topological materials
- Research theme 2, exciton superfluids
- Research theme 3, light-transformed materials
- Enabling technology A, atomically-thin materials
- Enabling technology B, nano-device fabrication

**Isabela Alves de Castro**
Alumnus, now at Alcoa

**Ivan Herrera**
Swinburne University

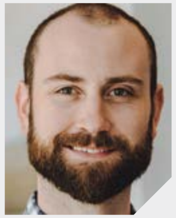
**Jackson Smith**
RMIT University

**Karina Hudson**
University of New South Wales



**Kun Qi**
Monash University

**Maciej Pieczarka**
Australian National University



**Matt Reeves**
University of Queensland

**Matthew Rendell**
University of New South Wales

**Pankaj Bhalla**
Beijing Computational Science Research Center

**Pankaj Sharma**
University of New South Wales

**Paul Atkin**
RMIT University

**Peggy Qi Zhang**
University of New South Wales

**Samuel Bladwell**
University of New South Wales

**Sascha Hoinka**
Swinburne University

**Shaun Johnstone**
Monash University

**Shilpa Sanwlani**
Swinburne University

**Shivananju Bannur Nanjunda**
Monash University

**Steven Barrow**
Alumnus, RMIT University

**Stuart Earl**
Swinburne University

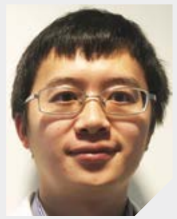
**Weizhe Liu**
Monash University

**Yun Suk Eo**
University of Maryland

**Yuefeng Yin**
Monash University

**Yupeng Zhang**
Alumnus, now at Shenzhen University

**Zengji Yue**
University of Wollongong



**Zhigao Dai**
Monash University

**Ziyu Wang**
University of New South Wales

## PHD STUDENTS

**Chang Liu**
Monash University

**Cheng Tan**
RMIT University

**Chutian Wang**
Monash University

**Dhaneesh Gopalakrishnan**
Monash University

**Fan Ji**
University of New South Wales

**Fei Hou**
University of New South Wales

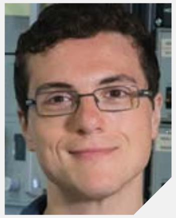
**Hanqing Yin**
Monash University

**Haoran Mu**
Monash University

**Hareem Khan**
RMIT University

**Hong Liu**
University of New South Wales

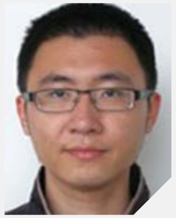
**Jackson Wong**
University of New South Wales



**James Collins**
Monash University

**Jesse Vaitkus**
RMIT University

**Jiali Zeng**
University of New South Wales

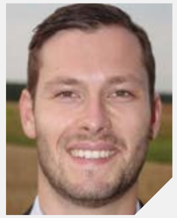


**Jialu Zheng**
Monash University

**Lawrence Farrar**
RMIT University

**Marina Castelli**
Monash University

**Maryam Boozarjmehr**
Australian National University



**Matthias Wurdack**
Australian National University

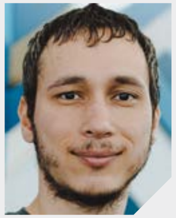
**LEGEND**

- 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

**Nuriyah Aloufi**
RMIT University

**Oliver Paull**
University of New South Wales

**Oliver Sandberg**
University of Queensland



**Pavel Kolesnichenko**
Swinburne University

**Qingdong Ou**
Monash University

**Rebecca Orrell-Trigg**
University of New South Wales

**Samuel Wilkinson**
RMIT University

**Stuart Burns**
University of New South Wales

**Sultan Albarakati**
RMIT University

**Tatek Lemma**
Swinburne University

**Tinghe Yun**
Monash University

**Tommy Bartolo**
RMIT University

**Tyson Peppler**
Swinburne University

**Vivasha Govinden**
University of New South Wales

**Wafa Afzal**
University of Wollongong

**Weiyao Zhao**
University of Wollongong

**Wenzhi Yu**
Monash University

**Yonatan Ashlea Alava**
University of New South Wales

**Yun Li**
Monash University

**Zhi-Tao Deng**
University of Queensland

**Zhichen Wan**
Monash University

> “I enjoy this field of research because there is so much that needs to be explored experimentally. It is a relatively new field, with a lot of unanswered questions.”
>
> **Wafa Afzal**
> FLEET PhD student

PROF ALEX HAMILTON

**Leader, Research theme 1**

*UNSW*

*"FLEET enables our researchers to tackle big challenges by working with scientists all over Australia"*

Expertise: electronic conduction in two-dimensional (2D) and nanoscale transistors, spin-orbit interactions, behaviour of holes in semiconductor nanostructures

Research outputs: 210+ papers, 3700+ citations, h-index 30

# 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 edge paths, they conduct electrons strictly 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.

For the new technology to become a viable alternative to traditional transistors, the desired properties must be achievable at room temperature – there's no point in saving energy on transistor switching if you have to use even more energy to keep the system supercold.

Topological transistors would 'switch', just as a traditional transistor does.

Applying a controlling voltage would switch the edge paths of the topological material between being a topological insulator ('on') and a conventional insulator ('off').

Approaches used are:

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

*PhD student Vivasha Govinden (UNSW) studies ferroelectric coupling, seeking an enhanced electromechanical response that could be used in future nanoelectronic sensors and electronics.*

## IN 2019, FLEET WILL:

- Develop techniques to electrically probe topological crystals grown in high-vacuum chambers
- Develop new theoretical techniques and models to understand and predict the electronic properties of topological materials
- Fabricate artificial crystals out of conventional semiconductors.

## 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

**quantum anomalous Hall effect (QAHE)** A magnetic effect giving a material conducting edges carrying current in one direction only, completely without resistance

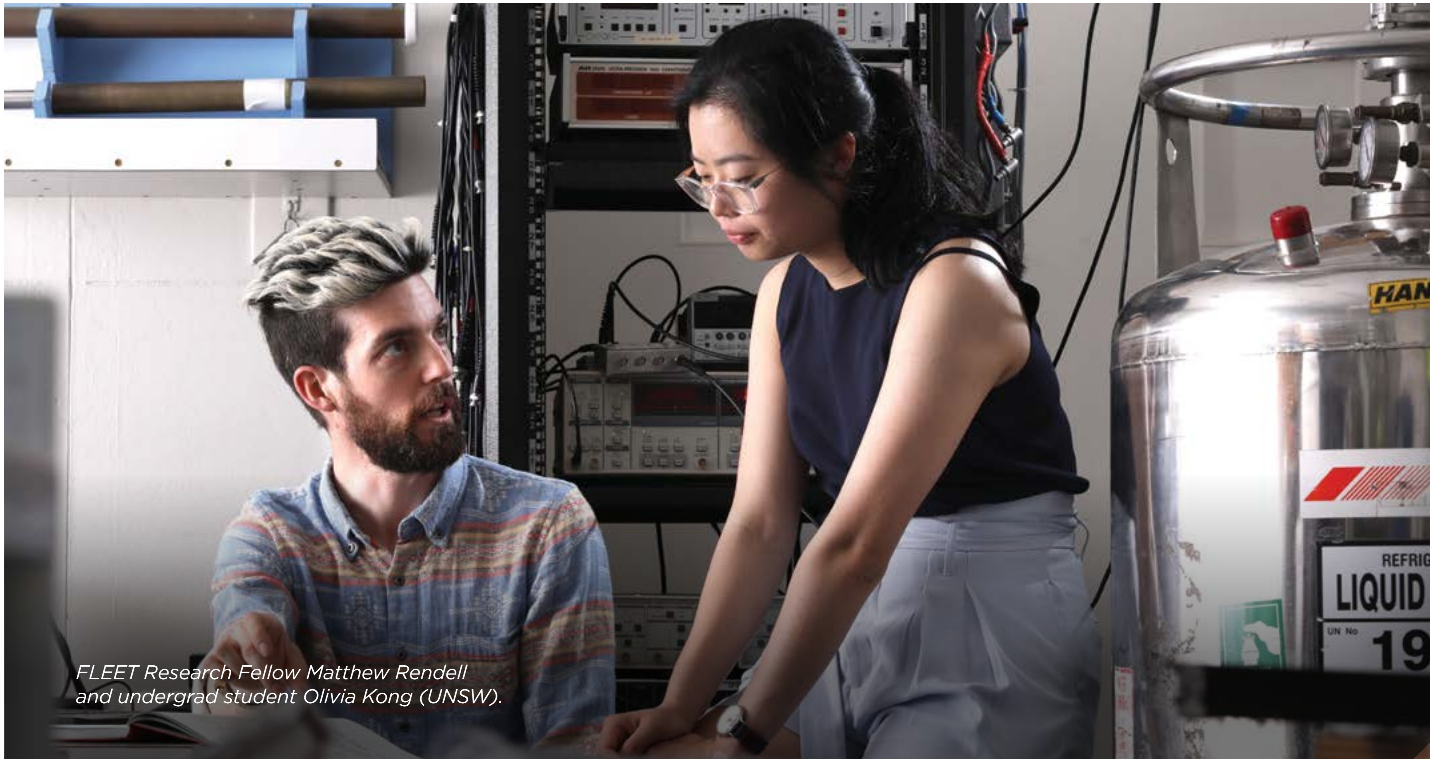
**spin-orbit coupling** The interaction between electrons' movement and their inherent angular momentum, which drives topological effects

## DID YOU KNOW...

*Information and communication technology (ICT) now contribute as much to climate change as the aviation industry.*

## 2018 HIGHLIGHTS

- First demonstration of electrical switching of a material from a normal to a topological insulator, using an electric field, a key step towards making a topological transistor **(see case study, p26)**
- New, fundamental theoretical work to understand the spin-orbit interaction that is behind topological materials, showing that spin-orbit interactions can significantly alter the Hall effect
- Development of a new photodetector based on the topological crystalline insulator SnTe
- Proposal for new superconducting device for routing electronic signals used in quantum circuits.

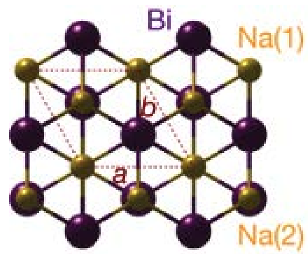


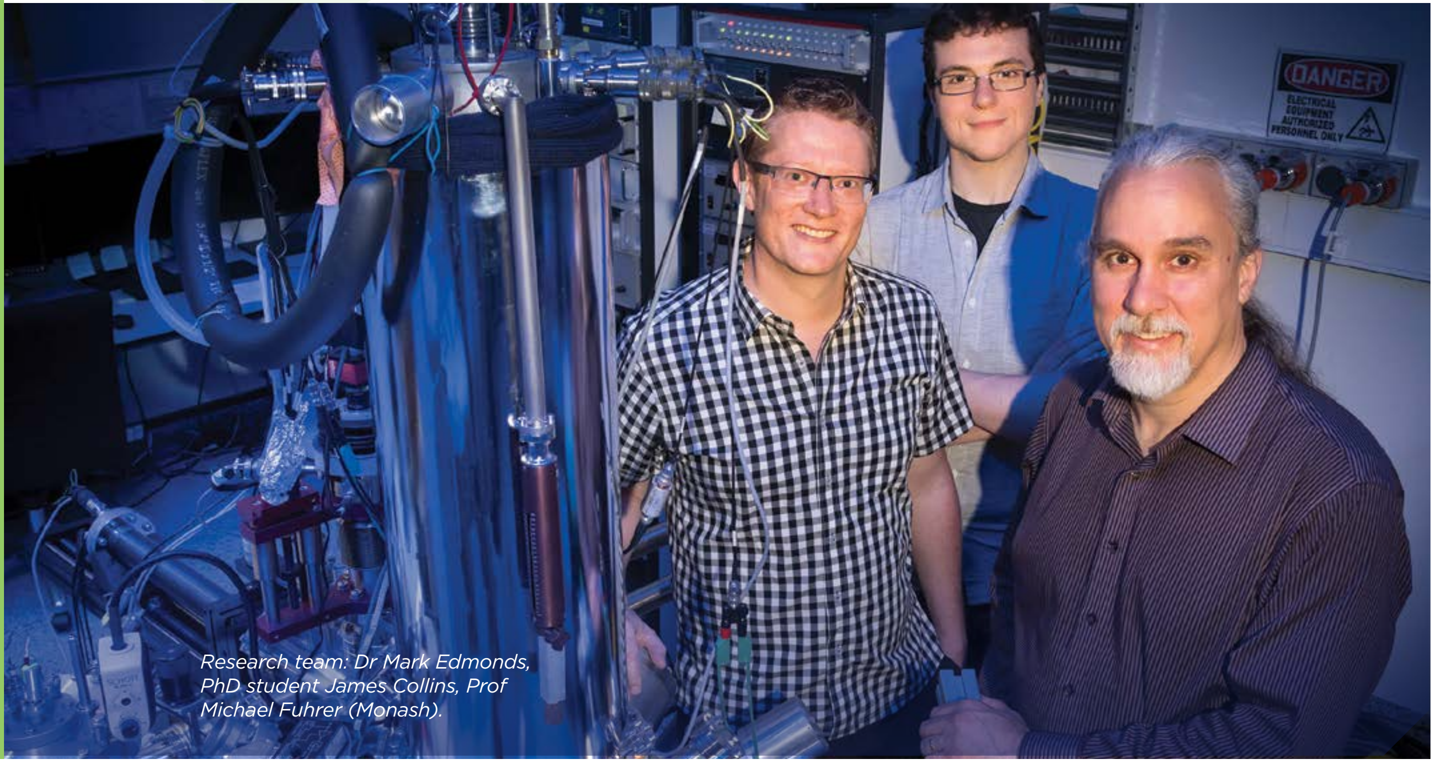
*FLEET Research Fellow Matthew Rendell and undergrad student Olivia Kong (UNSW).*

CASE STUDY

> This new switch works on a fundamentally different principle than the transistors in today's computers. We envision such switches facilitating a completely new computing technology, which uses lower energy.

**Dr Mark Edmonds**
FLEET Scientific AI,
Monash University




*Research team: Dr Mark Edmonds, PhD student James Collins, Prof Michael Fuhrer (Monash).*

# SWITCHING TOPOLOGICAL STATE OFF AND ON: STEP TOWARDS A TOPOLOGICAL TRANSISTOR

**FLEET researchers achieve world first: successfully 'switching' a topological material, via application of an electric field.**

This success represents the first step in creating a functioning topological transistor – a key goal of FLEET's Research theme 1.

"In a topological insulator's edge paths, electrons can only travel in one direction," explains lead author Dr Mark Edmonds. "And this means there can be no 'back-scattering', which is what causes electrical resistance in conventional electrical conductors."

Unlike conventional electrical conductors, such topological edge paths can carry electrical current with near-zero dissipation of energy, meaning that topological transistors could burn much less energy than conventional electronics. They could also potentially switch much faster.

Topological materials would form a transistor's active 'channel' component, and would switch between open (0) and closed (1) to accomplish the binary operation used in computing.

The electric field induces a quantum transition from topological insulator to conventional insulator.

To be a viable alternative to current, silicon-based technology (CMOS), topological transistors must:

- operate at room temperature (without the need for expensive supercooling)
- 'switch' between conducting (1) and non-conducting (0)
- switch extremely rapidly, by application of an electric field.

While switchable topological insulators have been proposed in theory, this is the first time that experiment has proved that a material can switch at room temperature, which is crucial for any viable replacement technology.

(In this study, experiments were conducted at cryogenic temperatures, but the large bandgap measured confirms that the material will switch properly at room temperatures.)

The material $Na_3Bi$ is a topological Dirac semimetal (TDS). These materials have long been considered promising systems in which to look for topological field-effect switching, as they lie at the boundary between conventional and topological phases.

The study found that when $Na_3Bi$ is made 'atomically thin' (that is, only a few layers of atoms in thickness), it is possible to open an electronic band gap, turning the material into an insulator. This bandgap is an essential component in any electronic switch.

Crystal growth and measurements were conducted in FLEET's laboratories at Monash University, and at the Advanced Light Source (Lawrence Berkeley National Laboratory), in California, where ARPES (angle-resolved photoemission spectroscopy) measurements were made. Research was also undertaken at the Australian Synchrotron.

This addresses FLEET milestone 1.1; **see p93**.

The study was published in *Nature* in December 2018, vol. 564 **(see publication 10, p104)**.

**More at FLEET.org.au/topological-switching**

## COLLABORATING FLEET PERSONNEL:

- Associate Investigator Mark Edmonds (Monash)
- PhD student James Collins (Monash)
- Partner Investigator Anton Tadich (Australian Synchrotron)
- PhD student Chang Liu (Monash)
- Associate Investigator Shaffique Adam (Yale-NUS)
- Chief Investigator Michael Fuhrer (Monash)

## NEW PHYSICS: TOPOLOGICAL MATERIALS AND THE 2016 NOBEL PRIZE IN PHYSICS

Topological materials represent a paradigm shift in material science, first proposed in 1987 and only demonstrated in the lab in the last decade.

The quantum anomalous Hall effect (QAHE) was achieved in the laboratory at Tsinghua University in 2013 by Prof Qi-Kun Xue, now a FLEET Partner Investigator and leading the Centre's collaboration with Tsinghua University.

This 2013 discovery showed that current could be carried with no measurable dissipation and opened up the field of topological electronics being investigated at FLEET.

The importance of topological materials was recognised by the 2016 Nobel Prize in Physics, awarded to Michael Kosterlitz, Duncan Haldane and David Thouless.

A/PROF ELENA OSTROVSKAYA

**Leader, Research theme 2**

*Australian National University*

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

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

Research outputs: 130+ papers, 3 book chapters, 3800+ citations, h-index 33

# 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.

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.

## IN 2019, FLEET WILL:

- Fabricate microcavities with transition metal dichalcogenides (TMDs) and observe strong light-matter coupling
- Characterise low-energy interactions in exciton systems
- Investigate designs to support twin-layer excitons
- Build on collaborations between FLEET nodes to design, fabricate and characterise heterostructures for theme 2 research.

## 2018 HIGHLIGHTS

- Puzzling results explained: discovery of multiband mechanism for sign reversal of Coulomb drag in bi-layer graphene structures **(see p30)**
- First 'single-shot' observation of exciton-polariton condensation; an insight into non-equilibrium, solid-state condensation **(see p32)**
- Observation of hybrid exciton-polariton condensation in a quantum-well/TMD-monolayer microcavity; the first step towards condensation of exciton-polaritons in a TMD monolayer, a key FLEET goal.

## 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.**

## 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

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

**dissipationless current** Electric current that flows without wasted dissipation of energy

**exciton** 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

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

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

*Theme 2 researchers Dr David Colas (UQ) and Dr Eliezer Estrecho (ANU).*

CASE STUDY

# PUZZLING RESULTS EXPLAINED IN EXCITON EXPERIMENT

**Taking a multiband approach explains electron-hole 'reverse drag'**

In 2018, a FLEET theoretical study finally unlocked a previously mysterious result that seemed to show coupled holes and electrons moving in the opposite direction to that predicted by theory.

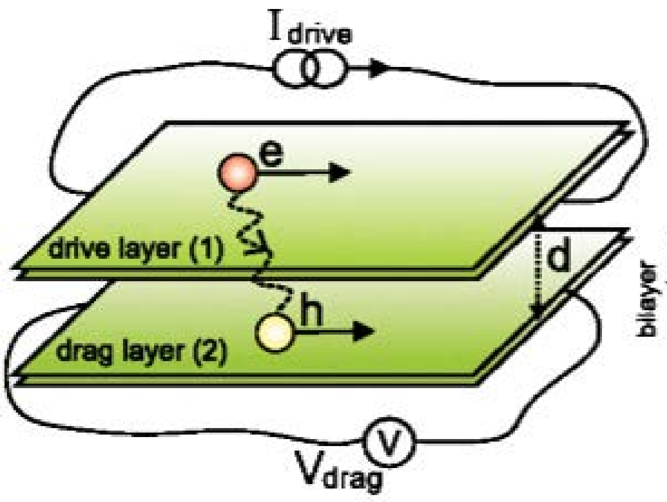
The FLEET study showed that this seemingly contradictory phenomenon is associated with the bandgap in dual-layer graphene structures, a bandgap which is very much smaller than in conventional semiconductors.

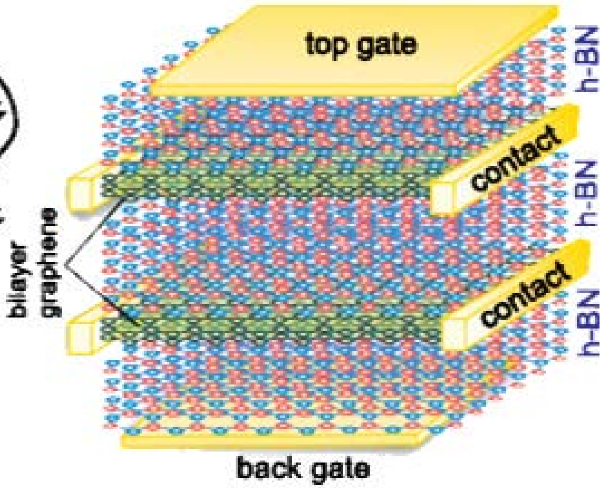
The study authors, which included FLEET Partner Investigator Prof David Neilson at the University of Camerino (Italy) and FLEET CI Prof Alex Hamilton at UNSW, found that the new multiband theory fully explained the previously inexplicable experimental results.

Exciton transport offers great promise to researchers, including the potential for ultra-low dissipation future electronics.

In an indirect exciton, free electrons in one two-dimensional (2D) sheet can be electrostatically bound to 'holes' (effectively, absent electrons) in a neighbouring 2D sheet.

Because the electrons and holes are each confined to their own 2D sheets, they cannot recombine, but they can electrically bind together if the two 2D sheets are very close (a few nanometres).




*Left: An electron (e) accelerated in the top sheet causes a hole (h) in the lower sheet to be accelerated.*

*Right: Device schematic: one sheet of graphene carries electrons, the other, separated by insulating hBN, carries holes.*

If electrons in the top ('drive') sheet are accelerated by an applied voltage, then each partnering hole in the lower ('drag') sheet can be 'dragged' by its electron.

A goal in such a mechanism is for the exciton to remain bound, and to travel as a superfluid, a quantum state with zero viscosity, and thus without wasted dissipation of energy.

To achieve this superfluid state, precisely-engineered 2D materials must be kept only a few nanometres apart.

An insulating sheet between two sheets of atomically-thin (2D) graphene prevents recombination of electrons and holes.

Passing a current through one sheet and measuring the drag signal in the other sheet allows experimenters to measure the interactions between electrons in one sheet and holes in the other, and to ultimately detect a clear signature of superfluid formation.

However, experiments published in 2016 showed extremely puzzling results. Under certain experimental conditions, the Coulomb drag was found to be negative. That is, moving an electron in one direction caused the hole in the other sheet to move in the opposite direction!

These results could not be explained by existing theories.

The FLEET study explained these puzzling results using crucial multi-band processes that had not previously been considered in theoretical models.

Bi-layer graphene has a very small bandgap, which can be changed by application of an electric field.

The calculation of transport in multiple bands was the 'missing link' marrying theory to experimental results. The strange 'negative drag' happens when available thermal energy approaches the bandgap energy.

This addresses FLEET milestone 1.2; **see p93**.

The study was published in *Physical Review Letters* in July 2018, vol. 121 **(see publication 57, p106)**.

## COLLABORATING FLEET PERSONNEL:

- Chief Investigator Alex Hamilton (UNSW)
- Partner Investigator David Neilson (University of Camerino)

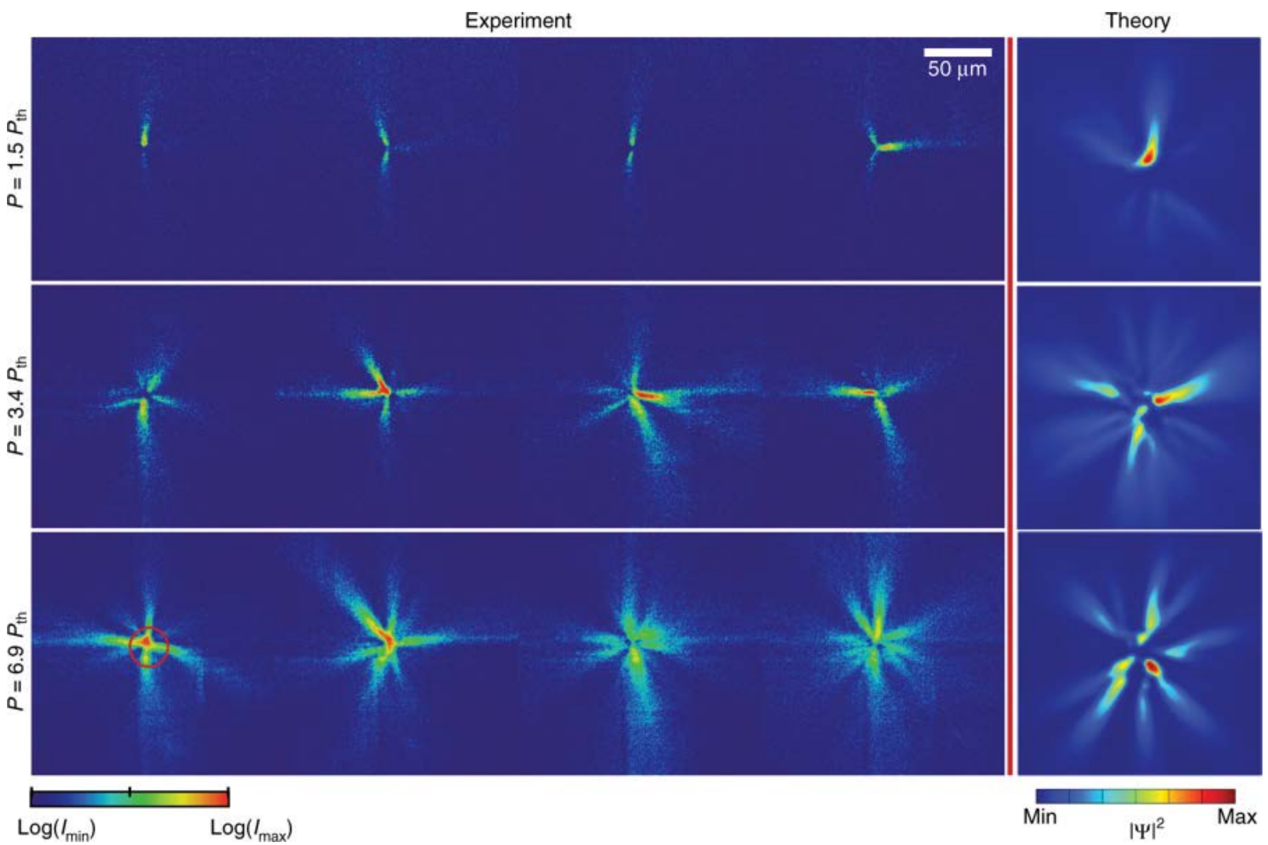
**More at FLEET.org.au/puzzling-excitons**

This research area allows us to combine very deep, fundamental questions about the nature of quantum phase transitions in a solid state and, at the same time, is very promising for future applications in low-energy electronics.

**A/Prof Elena Ostrovskaya**
FLEET Chief Investigator, ANU

I love this field of research because it gives us so much freedom and flexibility in designing the experiments and testing novel ideas in exciton-polariton superfluids.

**Dr Harley Scammell**
FLEET Research Fellow UNSW




*Single-shot condensation of polaritons. Theory (on the right) shows remarkable agreement with experiment (left).*

# FIRST EXCITON SNAPSHOT

**First-ever 'snapshot' of Bose-Einstein condensation achieved in FLEET/ANU study**

Previously, observations of exciton-polaritons in a Bose-Einstein condensate have been limited to statistical averaging over millions of condensation events.

'Snapshot' imaging of polaritons forming a condensate in a typical inorganic semiconductor was considered impossible.

In 2018, FLEET researchers at ANU led an international study imaging exciton-polaritons for the first time as a 'single shot', rather than averaging.

"This offers a unique opportunity to understand the details of Bose-Einstein condensation of exciton-polaritons," explains lead author Dr Eliezer Estrecho.

Such fundamental advances also aid FLEET's research on excitonic condensation and superfluidity as a mechanism for electronic conduction without wasted dissipation of energy.

Exciton-polaritons are hybrid particles that are part matter and part light, bound together by strong coupling of photons and electron-hole pairs (excitons) within a semiconductor microcavity.

However, because exciton-polariton lifetimes are measured in picoseconds (trillionths of a second), previously observations have always averaged over a million lifetimes of exciton-polaritons.

This is like taking a long exposure of moving objects: you get a blurred image.

The ANU team made sure that their sensitive camera captures only one lifetime or 'single shot' of the condensate, enabling them to observe never-before-seen behaviour of exciton-polaritons.

The single-shot imaging is performed by analysing photoluminescence caused by the decay of exciton-polaritons, a technique thought to be impossible in inorganic microcavities because emissions simply weren't bright enough.

Usually, the density of exciton-polaritons trapped in inorganic microcavities is too low to be detected in single-shot mode, partly because exciton-polaritons do not live long enough for the density to build up.

To get a better signal, the team used ultra-high-quality samples designed and made by their collaborators in the USA, extending the lifetime of polaritons by an order of magnitude and pushing the density high enough for the sensitive camera to detect.

The imaging revealed that, contrary to the smooth condensate observed in averaged experiments, the condensate actually forms filaments whose orientation varies from shot to shot.

The study found remarkable agreement between experiment and numerical simulations, validating the background theory of exciton-polariton condensate dynamics.

The work paves the way for further fundamental studies of quantum phase transitions and non-equilibrium condensation in solid-state systems.

The single-shot experiments could prove critical for our understanding of the fundamental (and still debated) nature of the condensed phase in these systems.

This addresses FLEET milestone 1.2; **see p93**.

The study was published in *Nature Communications* in August 2018, vol. 9 **(see publication 13, p104)**.

**More at FLEET.org.au/exciton-snapshot**

> Single-shot imaging of a polariton condensate was thought impossible, but we still tried, and succeeded, finding interesting effects never observed in experiments before.
>
> **Dr Eliezer Estrecho**
> FLEET Research Fellow, ANU

## COLLABORATING FLEET PERSONNEL:

- Research Fellow Eliezer Estrecho (ANU)
- Chief Investigator Elena Ostrovskaya (ANU)

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, nonlinear atoms dynamics, atomic gas superfluidity, atomtronics, non-linear atom optics

Research outputs: 100+ papers, 5000+ citations, h-index 31

# 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, 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.

> Because this research is so interdisciplinary, I am able to connect multiple research directions into one and see a bigger picture, making me a more-rounded scientist.
>
> **Pavel Kolesnichenko**
> FLEET PhD student, Swinburne

## IN 2019, FLEET WILL:

- Begin construction of quantum gas microscope facility at Swinburne University to study dipolar atoms in optical lattices
- Engineer wave interactions via Feshbach resonances in a 2D Fermi gas to ultimately realise topological superfluidity
- Further develop femtosecond band control in 2D solid-state material for engineering of Floquet topological insulators
- Investigate, with ultracold atoms, the effect of interactions between particles in the quantum kicked rotor to test theories of many-body dynamical localisation and insulator behaviour of materials
- Launch experimental infrastructure to study ultra-fast, light-induced dynamics and light-driven topological phase transitions in optically active materials
- Develop theory of driven dissipative superfluid to improve understanding of non-equilibrium transport
- Further develop a general framework for understanding behaviour of quasiparticles and low-energy excitation
- Demonstrate spin-orbit coupling in periodically-driven atomic system
- Investigate the utility of time crystals in the context of Floquet states.

## 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

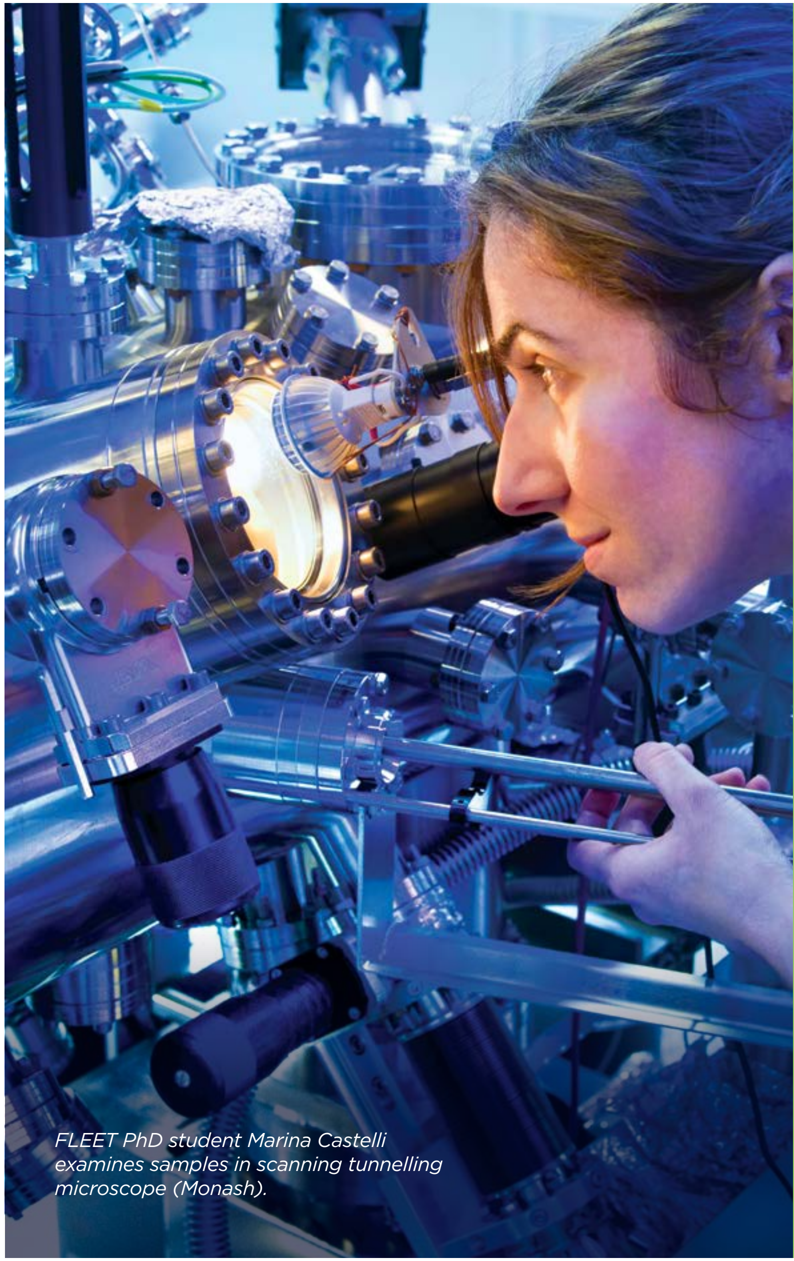
**superfluid** A quantum state in which particles flow without encountering any resistance to their motion. Both excitons and exciton-polaritons can flow in a superfluid

## 2018 HIGHLIGHTS

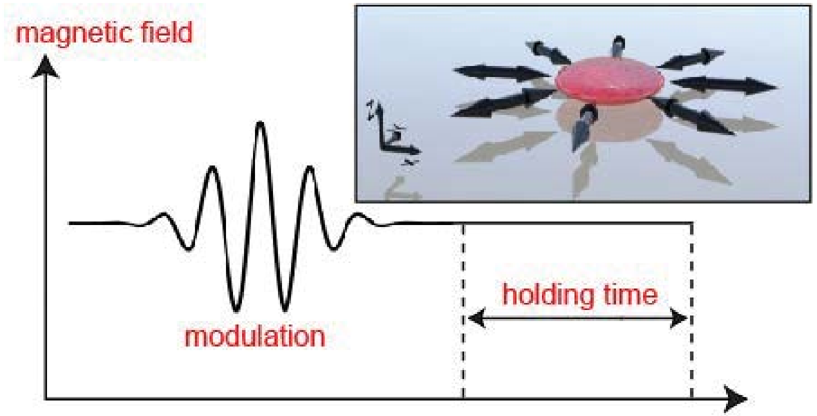
- Observation of quantum anomaly in an ultra-cold 2D Fermi gas **(see case study p36)**
- Comprehensive explanation of the meaning of negative effective mass in spin-orbit coupled BECs **(see case study p38)**, improving understanding of atom transport in materials due to transient applied forces or impulses
- Realisation of negative absolute temperature distribution of vortices in a superfluid, verified in twin Monash/University of Queensland studies
- Control of Floquet-Bloch bands with femtosecond laser pulses, indicating that Floquet-Bloch states are minimally affected by finite pulse duration (down to 30 fs): a step toward dynamic band-structure engineering of materials
- Development of a new theoretical approach for finite-temperature dynamics, improving understanding of impurity effects at non-zero temperature, a phenomena common to all materials
- Theoretical study of quantum battery, indicating that quantum effects can improve charging of a spintronic battery with implications for new approaches of driven, dissipationless conduction, as well as faster switching of magnetic materials.

## DID YOU KNOW...

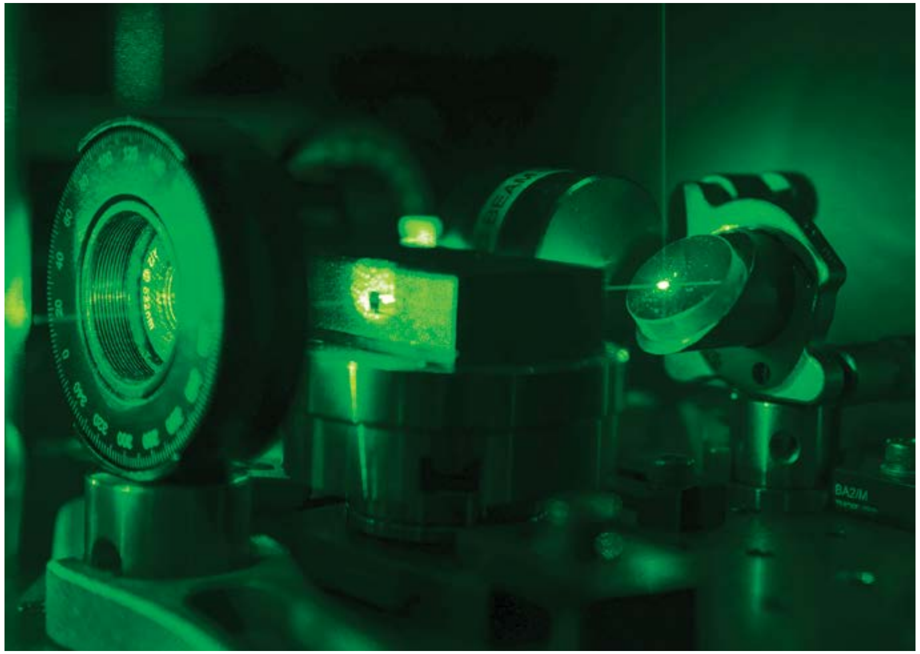
**FLEET researchers cool atomic gases to only a few nanoKelvins above Absolute Zero, which is a billion times colder than interstellar space.**



*FLEET PhD student Marina Castelli examines samples in scanning tunnelling microscope (Monash).*




*An oscillating magnetic field is applied to an atomic gas (shown upper right), causing it's size to oscillate in two dimensions.*



*Laser equipment (532nm) at Swinburne University of Technology, used to confine the atomic gas.*

# BREAKING A CLASSICAL SYMMETRY WITH ULTRA-COLD ATOMS

**Scaling symmetry in a 2D Fermi gas breaks down with strong interactions between particles**

A 2018 FLEET study of ultra-cold atomic gases – a billionth the temperature of outer space – unlocked new, fundamental quantum effects.

In this study, a simple, classical theory of atomic interaction is shown to be break down, and a more-sophisticated quantum treatment is required.

The researchers at Swinburne University of Technology studied collective oscillations in ultra-cold atomic gases – identifying where quantum effects occur to 'break' symmetries predicted by classical physics.

They also observed the transition between two-dimensional (2D) behaviour and three-dimensional (3D) behaviour.

"Fundamental discoveries made from such observations will inform FLEET's search for electronic conduction without wasted dissipation of energy," explained study author Prof Chris Vale.

Two-dimensional materials exhibit many novel physical properties and are keenly studied for their potential uses; for example, in ultra-low energy electronics.

However, strong correlations and imperfections within 2D materials make them difficult to understand theoretically. Quantum gases of ultra-cold atoms help unlock the fundamental physics of 2D materials, as well as uncovering new phenomena not readily accessible in other systems.

Experiments performed on quantum gases of ultra-cold neutral atoms enhance our understanding of phase transitions and the effects of interactions between particles.

This improved ability, understanding and control of phase transitions will have a direct application in FLEET's development of future low-energy, topologically-based electronics.

'Symmetries' are an essential ingredient in the formulation of many physics theories, allowing simplified descriptions by identifying which factors *don't* modify a system's underlying physical properties.

For example, in a 'scale invariant' system, changing the distances between its particles doesn't alter the behaviour of a material but merely 'scales' it by an appropriate factor.

Gases of ultra-cold atoms confined to a two-dimensional plane allowed FLEET researchers to explore regimes where that 'scaling symmetry' can be broken by quantum effects.

Researchers studied a strongly-interacting 2D gas of lithium atoms, measuring the frequency of a radial oscillation known as the 'breathing mode', which is a window to the gas's thermodynamic equation of state and whose frequency is set by the gas's compressibility.

The breathing mode is the gas's lowest energy collective oscillation, and as long as scaling symmetry exists, the breathing mode should always occur at the same frequency (exactly twice the harmonic confinement frequency).

The study confirmed that scaling symmetry is broken in the presence of strong interactions between particles, affecting the thermodynamic relation between the pressure and density.

This is called a quantum anomaly, being something that occurs when a symmetry that is present in a classical theory is broken in the corresponding quantum theory.

This addresses FLEET milestone 1.1, as well as working towards milestones 1.2 and 1.3; **see p93**.

The study was published in *Physical Review Letters* in September 2018, vol. 121 **(see publication 32, p105)**.

**More at FLEET.org.au/breaking-symmetry**

> FLEET inspires me to do new research and to seek new collaborations.
>
> **Dr Jesper Levinson**
> FLEET Scientific AI,
> Monash University

## COLLABORATING FLEET PERSONNEL:

- Associate Investigator Paul Dyke (Swinburne)
- Research Fellow Ivan Herrera (Swinburne)
- Research Fellow Sasha Hoinka (Swinburne)
- Chief Investigator Chris Vale (Swinburne)
- Chief Investigator Meera Parish (Monash)
- Associate Investigator Jesper Levinson (Monash)

# CLARIFYING EFFECTS OF NEGATIVE MASS

**FLEET study clarifies understanding of negative mass**

A FLEET study in 2018 has helped to clarify understanding of mass effects in ultra-cold gases.

When we think of 'mass', we usually consider the 'inertial' mass – the resistance of a body to acceleration due to an applied force.

For a moving object, its mass is then a simple relationship between momentum applied to it and the velocity it acquires.

However, in some situations, this relationship is not simply proportional and can depend on the impulse applied to the object. Physicists then talk about 'effective' mass, which can even be negative.

In such a case, an object would move in a completely non-intuitive way when acted on by a force.

"Imagine a soccer ball: you give it a first kick to get closer to the goal; you then give it an extra kick to score but, instead of accelerating, the ball slows down! You're a bit puzzled, so you decide to kick the ball even harder, and it now moves towards your foot and not away from it!" explains the lead author of the study, Dr David Colas (University of Queensland).

*Dr David Colas (UQ) plans to name his next paper "Assisted negative-mass air soccer".*

Negative masses can be achieved experimentally in various systems; for example, in ultra-cold atomic gases.

The UQ theoretical research expanded upon an earlier study at Washington State University that demonstrated a negative mass effect in the expansion of an ultra-cold atomic gas, nicely illustrating the versatility and great tunability of the UQ platform.

The UQ researchers clarified the effects associated to the different types of negative mass and identified the striking 'self-interfering effect' in the atomic condensate.

"To carry on with the soccer ball analogy, imagine that if you kick it too hard, you will squeeze it against your foot for a bit. When the ball leaves your boot, it re-expands and you see that the front part of the ball will eventually travel slower than its bottom part. The ball then interferes with itself," continues Dr Colas.

Negative mass effects can come out in different forms, such as self-interference. But one of the most striking is the backward propagation of a positive impulse: the hypothetical soccer ball that accelerates *towards* the kicker's boot, not away from it.

Clarification of the type of mass that is responsible for each observed phenomenon will avoid common misinterpretations about negative mass. Such clarification will help get negative mass research back on track.

This addresses FLEET milestone 1.1, as well as working towards milestones 1.2 and 1.3; **see p93**.

The study was published in *Physical Review Letters* in July 2018, vol. 121 **(see publication 9, p104)**.

**More at FLEET.org.au/negative-mass**

## COLLABORATING FLEET PERSONNEL:

- Research Fellow David Colas (UQ)
- Chief Investigator Matthew Davis (UQ)

> "The stability of funding allows for building a strong team for long-term projects. I like to think I do work of high quality, and it takes time for this to eventuate. Some very good stuff is coming in the next year or two."
>
> **Prof Matthew Davis**
> FLEET Chief Investigator, UQ

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: 460+ publications, 9900+ citations, h-index 48

# 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.

## IN 2019, FLEET WILL:

- Further increase temperature for topological surface states in three-dimensional (3D) topological insulators
- Continue to search for new magnetic systems for quantum anomalous Hall effect (QAHE) using modelling
- Work on new magnetic doping for anomalous Hall effect or QAHE
- Continue scanning tunnelling microscope study of atomically-thin systems
- Continue angle-resolved photoemission spectroscopy (ARPES) study of electronic structures.

## 2018 HIGHLIGHTS

- Collaborations between FLEET nodes to fabricate 2D materials for research
- Achieved topological surface states robust to 50 degrees Kelvin in chemically-modified $Sb_2Se_3$
- Discovery of new excitonic insulating state in atomically-thin antimony
- Discovery of ferroelectricity in 2D semiconductor $In_2Se_3$
- Successful fabrication of 2D oxides from liquid metals
- Fabrication of high-quality perovskite oxide heterostructures, realising new oxides stable only in ultra-thin form with promise for new topological oxides
- Discovery of first vdW hard ferromagnetic metal with near-square magnetic loop and strong perpendicular anisotropy
- Thickness dependence of tungsten ditelluride ($WTe_2$) – **see case study p44** below.

## DID YOU KNOW...

***FLEET scientists use materials that are 'atomically thin', ie, only one layer of atoms in thickness. These materials are also referred to as 'two dimensional' (2D).***

> FLEET's research goals are at the extreme cutting edge, and are super challenging from a physics perspective, both in simply gaining understanding, and in their execution. I have the feeling that we are at the forefront of something massive.

**Dr Daniel Sandoo**
FLEET Research Fellow,
UNSW

## DEFINITIONS

**graphene** A single 2D layer of carbon atoms

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

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

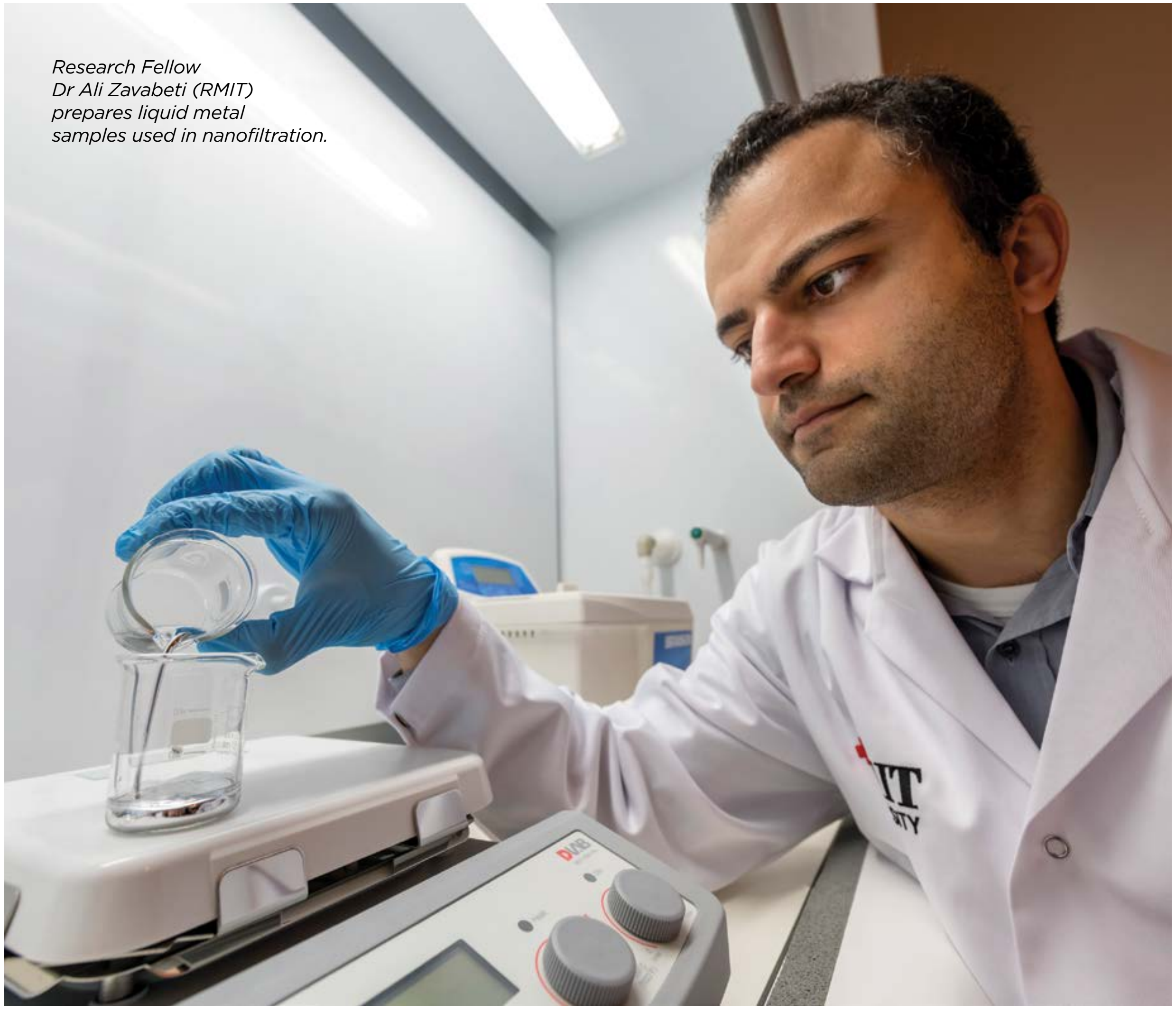
**monolayer** A single layer of material

**quantum anomalous Hall effect (QAHE)** A magnetic effect giving a material conducting edges carrying current in one direction only, completely without resistance

**van der Waals (vdW) material** A material naturally made of 2D layers, which can be isolated individually or stacked with other materials to form new structures


*PhD student Wafa Afzal (UOW) presenting her work on the magnetic state of atomically-thin materials.*

CASE STUDY



*Research Fellow Dr Ali Zavabeti (RMIT) prepares liquid metal samples used in nanofiltration.*

# RAPID NANOFILTER DEVELOPED FOR INSTANT CLEAN WATER

**Liquid metals the path to new nanofilter**

FLEET researchers have designed a rapid nanofilter that can clean dirty water over 100 times faster than current technology.

Simple to make and simple to scale up, the technology harnesses naturally-occurring nanostructures of aluminium hydroxide, grown on liquid-metal gallium.

This innovative technology can filter both heavy metals and oils from water at extraordinary speed.

FLEET Research Fellow Dr Ali Zavabeti (RMIT) explains that water contamination remains a significant challenge globally – one in nine people have no clean water close to home. “Heavy metal contamination causes serious health problems and children are particularly vulnerable,” Dr Zavabeti says.

“Our new nanofilter, made of stacked, atomically-thin sheets of aluminium hydroxide, is sustainable, environmentally friendly, scalable and low cost.

“We’ve shown it works to remove lead and oil from water, but we also know it has potential to target other common contaminants, such as mercury, sulfates and phosphates.

> This new nanofilter could be a cheap and ultra-fast solution to the problem of dirty water.
>
> **Dr Ali Zavabeti**
> FLEET Research Fellow, RMIT

The liquid-metal chemistry process developed by the researchers has potential applications across a range of industries, including electronics, membranes, optics and catalysis.

"The technique is potentially of significant industrial value, since it can be readily upscaled, the liquid metal can be reused, and the process requires only short reaction times and low temperatures," Dr Zavabeti says.

Project leader FLEET CI Prof Kourosh Kalantar-zadeh (UNSW, RMIT) says the liquid-metal chemistry used in the process enabled differently shaped nanostructures to be grown, either as atomically-thin sheets or nanofibrous structures.

"Growing these materials conventionally is power intensive, requires high temperatures and extensive processing times and uses toxic metals. Liquid-metal chemistry avoids all these issues so it's an outstanding alternative."

Water is added to a drop of a liquid metal. The skin is delaminated by hydrogen bubbles to form 2D sheets in the water, forming a hydrogel.

Experiments showed the nanofilter was efficient at removing lead from water that had been contaminated at over 13 times safe drinking levels, and was highly effective in separating oil from water.

The process generates no waste and requires just aluminium and water, with the liquid metals reused for each new batch of nanostructures.

The study was published in *Advanced Functional Materials* in September 2018, vol. 28 **(see publication 58, p106)**.

**More at FLEET.org.au/nano-filter**

## COLLABORATING FLEET PERSONNEL:

- Research Fellow Ali Zavabeti (RMIT)
- Alumnus Isabela Alves de Castro (now at Alcoa)
- Associate Investigator Jian-zhen Ou (RMIT)
- Alumnus Ben Carey (now at University of Munster)
- Associate Investigator Torben Daeneke (RMIT)
- Chief Investigator Kourosh Kalantar-zadeh (UNSW/RMIT)


*FLEET Research Fellow Feixiang Xiang (UNSW) studies 2D materials in collaboration with Centre colleagues at UOW.*

# WHY 2D? FINDING THE 2D–3D TRANSITION POINT

**Measuring thickness-dependent electronic properties**

A FLEET UNSW/Wollongong collaboration found a key transition point from three-dimensional (3D) to two-dimensional (2D) properties in 2018.

2D materials are useful for FLEET because constraining the movement of charge carriers (such as electrons) to two dimensions unlocks unusual quantum properties and useful electronic properties.

In essence, this means restricting electron movement to a range from a few nanometres to a few hundred nanometres.

Much can be learned by observing precisely at what thickness such new quantum effects emerge.

A 2018 FLEET study found this precise transition point in the promising material tungsten ditelluride ($WTe_2$) to be around 20 nanometres (that is, 20 millionths of a millimetre).

FLEET Research Fellow Dr Feixiang Xiang prepared thin $WTe_2$ films of different thickness, cleaved from a single high-purity crystal.

After studying $WTe_2$ thin films at the University of Wollongong (UOW), Dr Xiang used UNSW laboratories to fabricate the devices from thin-film samples and perform transport measurements using ultra-low-temperature and high-magnetic-field measurement facilities.

Quantum oscillation measurements performed in FLEET CI Prof Alex Hamilton's lab at UNSW showed how the material's band structure changed with decreasing thickness, and indicated a 3D–2D crossover when the sample thickness was reduced below 26 nm.

"This finding was very important," says Dr Xiang, who led the study at both UOW and UNSW, "because it pins down two critical length scales of the thickness-dependent electronic structure in $WTe_2$ thin films".

Analysis indicated that the area of Fermi pockets decreases in thinner samples, suggesting the overlap between the conduction band and valence band is becoming smaller. This not only explains the measured decrease of carrier density in a thinner sample, it suggests it is possible to open a bandgap and realise the 2D topological insulator in even thin samples, as has been predicted by theory, and observed in related compounds.

Constraining the movement of charge carriers to two dimensions results in very different electronic properties compared to 3D 'bulk' materials. This also suggests that additional different physical properties could happen at the monolayer limit – the transition point from 3D to 2D.

This addresses FLEET milestone 1.1; **see p93**.

The study was published in *Physical Review B* in July 2018, vol. 98 **(see publication 51, p106)**.

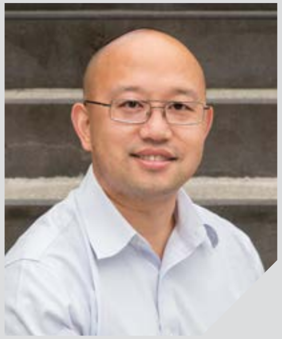
**More at FLEET.org.au/2D-transition**

## COLLABORATING FLEET PERSONNEL:

- Research Fellow Feixiang Xiang (UNSW)
- Chief Investigator Oleh Klochan (UNSW)
- Chief Investigator Alex Hamilton (UNSW)
- Chief Investigator Xiaolin Wang (UOW)

> I love working in FLEET... It's a broad scientific community with vastly different interests. This allows the bouncing around of some very crazy ideas.
>
> **Dr Oleh Klochan**
> FLEET Chief Investigator, UNSW

ENABLING TECHNOLOGY B



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, 2600+ citations, h-index 29

# ENABLING TECHNOLOGY B: NANO-DEVICE FABRICATION

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

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.

Nano-device 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.

"I love this research area because of the new ideas and new physics. This year we have got more ambitious in our research, and more motivated about our results."

**Cheng Tan**
FLEET PhD student,
RMIT

## IN 2019, FLEET WILL:

- Fabricate devices based on vdW heterostructures as a basis for quantum spin Hall effect (QSHE), quantum anomalous Hall effect (QAHE) and bi-layer exciton transistors
- Expand large-scale synthesis of 2D materials towards thin nanosheets with desired electrical, topological and magnetic properties
- Fabricate high-quality distributed Bragg reflector (DBR) microcavities.

## 2018 HIGHLIGHTS

- Refined glove box fabrication of vdW heterostructures
- Further developed liquid-metal synthesis of 2D materials, broadening the accessible range of 2D materials
- Demonstrated patterning of 2D electron gases, a platform to realise quantum spin Hall systems in oxide heterostructures
- Fabricated high-quality DBR microcavities, opening way to exciton-polariton condensation.

## 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

**distributed Bragg reflector (DBR) microcavity** Layered, di-electric mirror used to reflect a particular wavelength

**glove box** Sealed container allowing manipulation within a controlled atmosphere via gloves

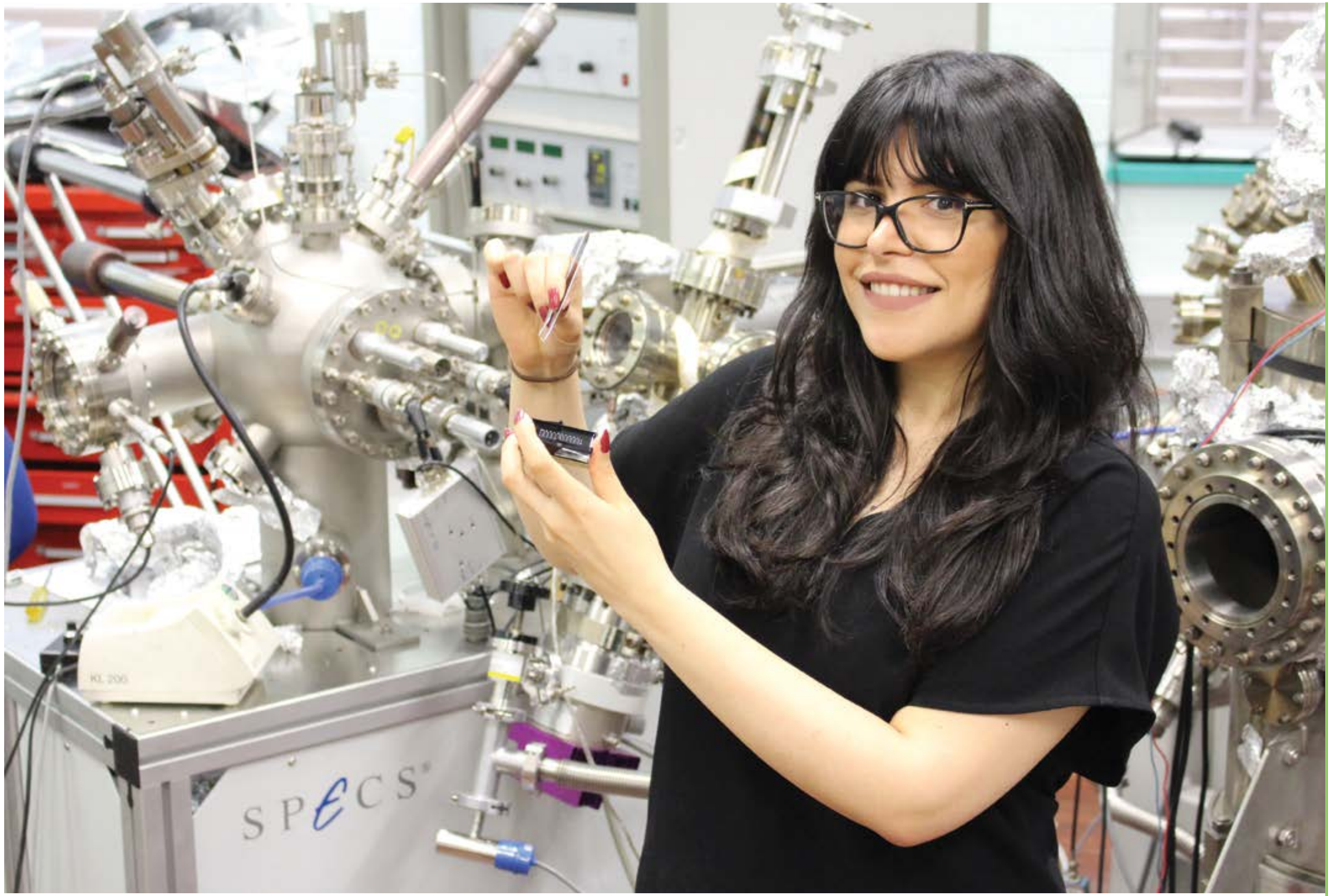
**heterostructure** A structure in which two dissimilar materials are brought together at a controlled interface

**quantum spin Hall effect (QSHE)** The spin-orbit interaction driven effect that gives a non-magnetic material conducting edges, which can carry current without resistance, as long as no magnetic disorder is present

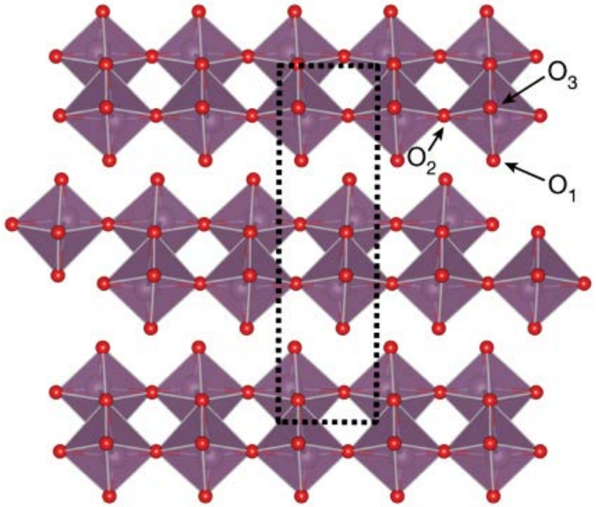
**quantum anomalous Hall effect (QAHE)** A magnetic version of the QSHE (above), in which conducting edges carry currents in only one direction, and are completely without resistance

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

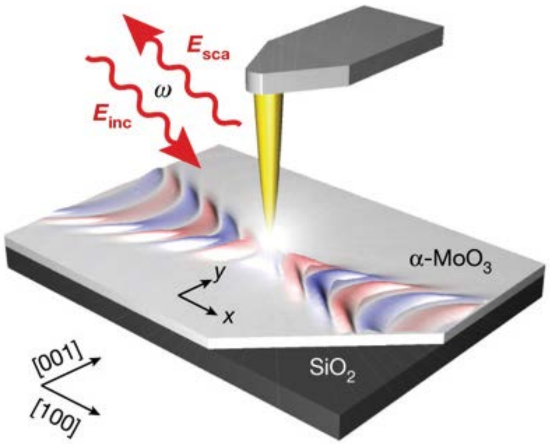
**van der Waals (vdW) heterostructure** A structure made by stacking layers of different van der Waals materials




*FLEET Research Fellow Golrokh Akhgar's expertise in 2D vdW heterostructures bridges Research theme 1 and Enabling technology B.*




*The structure of molybdenum trioxide is distorted by vdW interactions.*




*Near-field optical microscopy is a new method allowing improved imagery of polaritons.*

# LONG-LIVED 'SQUEEZED' NANOLIGHT DISCOVERED IN 2D MATERIAL

**Quantum breakthrough could deliver new ultra-low-energy electronics and communications technology**

An international collaboration led by FLEET's A/Prof Qiaoliang Bao (Monash University) used 'squeezed' light to make a significant quantum breakthrough.

In a world-first, the team observed a difference in the physical and mechanical properties of polaritons moving along the surface of a van der Waals (vdW) material in different directions.

Polaritons are a 'hybrid' particle, which can trap and manipulate light within micrometre-scale structures, while vdW materials are composed of multiple layers of two-dimensional (2D) structures.

The study found that squeezed light (nanolight) propagates only in specific directions along thin slabs of 2D molybdenum trioxide.

This nanolight also lives for an exceptionally long time, and thus could find applications in signal processing, sensing or heat management at the nanoscale.

Squeezing (confining) light to such a small size has been a major goal in nanophotonics for many years.

A successful strategy has been the use of polaritons, which are electromagnetic waves resulting from the coupling of light and matter. Particularly strong light squeezing can be achieved with polaritons at infrared frequencies in certain 2D materials.

However, polaritons in other materials have always been found to propagate along all directions of the material surface, thereby losing energy quite fast and limiting their usefulness.

Recently, it was predicted that polaritons could propagate 'anisotropically' along the surface of 2D materials (ie, their propagation was different in different directions).

In this case, the velocity and wavelength of the polaritons strongly depend on the direction in which they propagate. This property can lead to highly-directional polariton propagation in the form of nanoscale confined rays, which could find future applications in the fields of sensing, thermal heat management or maybe even quantum computing.

In addition to directional propagation, the study also revealed that the polaritons in this test material can have an extraordinarily long lifetime. Light seems to take a nanoscale 'highway', travelling in some directions with almost no obstacles. Polaritons were observed to live 40 times longer than the best similar measurements in graphene.

Researchers used a new microscope technique known as near-field optical microscopy, which has emerged alongside novel vdW materials over the past few years, to allow imaging of a variety of unique and even unexpected polaritons.

The current work is just the beginning of a series of studies focused on directional control and manipulation of light with the help of ultra-low-loss polaritons at the nanoscale. This work could benefit the development of more efficient nanophotonic devices for optical sensing and signal processing or thermal heat management.

Within FLEET, A/Prof Bao investigates waveguide-coupled 2D semiconductors and plasmon-coupled 2D materials and devices, focusing on the effect of confined-space light-matter interactions on the transport of electrons or other quasi-particles such as polaritons.

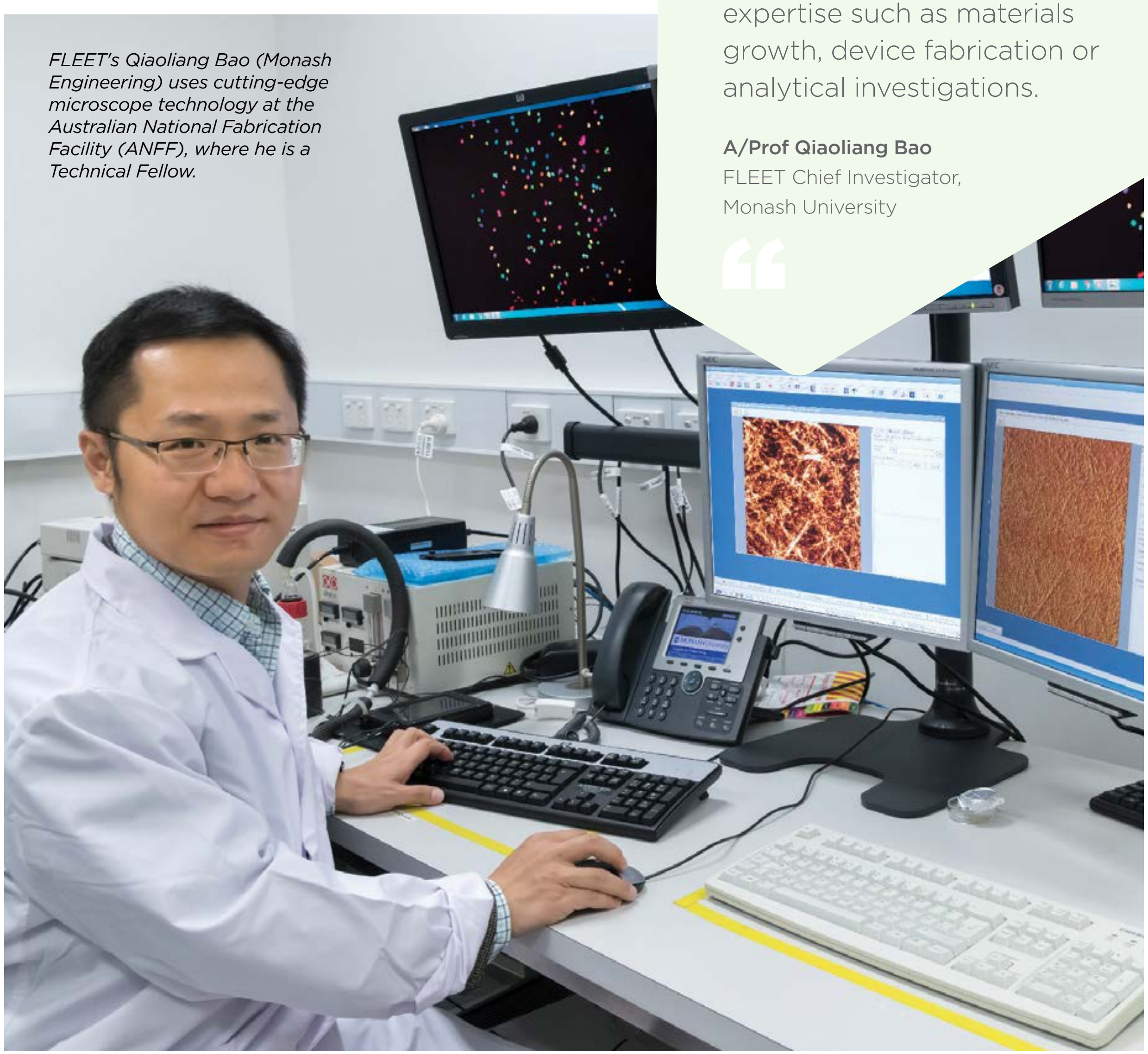
This addresses FLEET milestone 1.2; **see p93**.

The study was published in *Nature* in October 2018, vol. 562 **(see publication 26, p105)**.

**More at FLEET.org.au/polariton-breakthrough**

## COLLABORATING FLEET PERSONNEL:

- Research Fellow Zhigao Dai (Monash)
- Alumnus Yupeng Zhang (now at Shenzhen University)
- Chief Investigator Kourosh Kalantar-zadeh (UNSW/RMIT)
- Chief Investigator Qiaoliang Bao (Monash)



*FLEET's Qiaoliang Bao (Monash Engineering) uses cutting-edge microscope technology at the Australian National Fabrication Facility (ANFF), where he is a Technical Fellow.*

> Collaboration with different research groups is crucial to develop and further improve our capabilities, incorporating new areas of expertise such as materials growth, device fabrication or analytical investigations.
>
> **A/Prof Qiaoliang Bao**
> FLEET Chief Investigator, Monash University


*PhD student Nitu Syed and FLEET AI Dr Torben Daeneke (RMIT).*

# PUSHING PRINT ON LARGE-SCALE PIEZOELECTRICS

**First ever large-scale 2D surface deposition of piezoelectric material — this simple, inexpensive technique opens new fields for piezo-sensors and energy harvesting**

In 2018, FLEET researchers developed a revolutionary method to 'print' large-scale sheets of two-dimensional (2D) piezoelectric material, opening up new opportunities for piezo-sensors and energy harvesting.

Piezoelectric materials produce a small voltage when put under stress, and form the key component of ultra-sensitive pressure sensors, such as the motion-detectors in smartphones.

Importantly, this new, inexpensive fabrication process allows piezoelectric components to be directly integrated onto silicon chips, which has not previously been possible. This will significantly reduce manufacturing costs.

Now, FLEET researchers at RMIT University have demonstrated a method to produce large-scale 2D gallium phosphate sheets that allows this material to be formed at large scales in low-cost, low-temperature manufacturing processes onto silicon substrates, or any other surface.

The material used, gallium phosphate ($GaPO_4$), is particularly useful in high temperatures or other harsh environments.

The revolutionary new method allows easy, inexpensive growth of large-area (several centimetres), wide-bandgap, 2D $GaPO_4$ nanosheets.

The new process is simple, scalable, low temperature and cost-effective, significantly expanding the range of materials available to industry at such scales and quality.

This simple, industry-compatible procedure to print large-surface-area 2D piezoelectric films onto any substrate offers tremendous opportunities for the development of piezo-sensors and energy harvesters.

Piezoelectric materials can convert applied mechanical force or strain into electrical energy. Such materials form the basis of sound and pressure sensors, embedded devices that are powered by vibration or bending, and even the simple 'piezo' lighter used for gas BBQs and stovetops.

Piezoelectric materials can also take advantage of the small voltages generated by tiny mechanical displacement, vibration, bending or stretching to power miniaturised devices.

Test materials were synthesised in RMIT's Micro Nano Research Facility (MNRF).

This addresses FLEET milestone 1.1; **see p93**.

The study was published in *Nature Communications* in September 2018, vol. 9 **(see publication 40, p105)**.

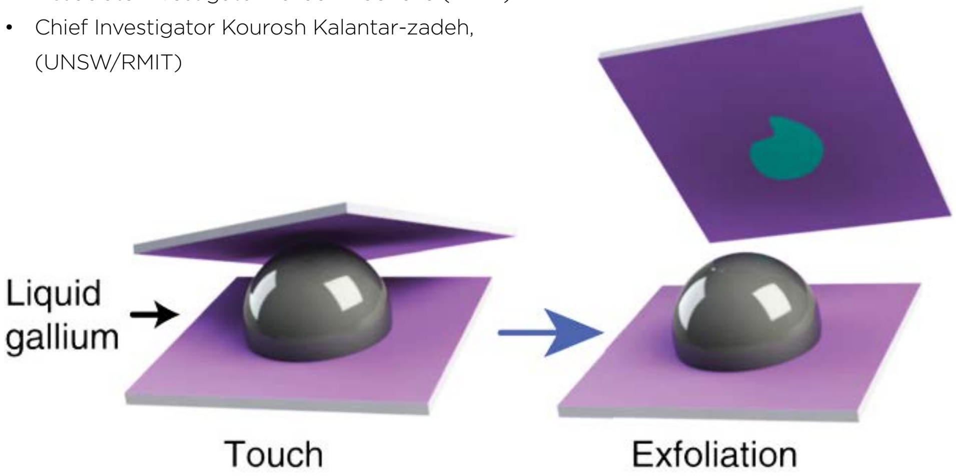
**More at FLEET.org.au/piezoelectric**

> 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

> As so often in science, this work builds on past successes. We adopted the liquid-metal material deposition technique we developed recently to create the 2D films.
>
> **Dr Torben Daeneke**
> FLEET Scientific Associate Investigator, RMIT

## COLLABORATING FLEET PERSONNEL:

- Research Fellow Ali Zavabeti (RMIT)
- Associate Investigator Jian-zhen Ou (RMIT)
- Alumnus Ben Carey (now at University of Munster)
- Associate Investigator Torben Daeneke (RMIT)
- Chief Investigator Kourosh Kalantar-zadeh, (UNSW/RMIT)




*FLEET has developed new, inexpensive methods for fabrication of useful 2D materials using liquid metals such as gallium.*

*FLEET Research Fellow Dr Sam Bladwell (UNSW) and visiting AI A/Prof Shaffique Adams (National University of Singapore).*

# 03 COLLABORATE

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

**NEW RESEARCH COLLABORATING ORGANISATIONS**
ESTABLISHED

**19**

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

**4**

**END-USER RELATIONSHIPS**
ESTABLISHED

**12**

> FLEET has transformed my scientific career. Working and collaborating and exchanging ideas with diverse people within FLEET motivates my research work and as I continue in FLEET I will continue to learn and grasp more knowledge.
>
> **Dr Shilpa Sanwlani**
> FLEET Research Fellow, Swinburne

**VISITS BY INTERNATIONAL STUDENTS AND ECRs** 4

**FLEET MEMBERS VISITING PARTNER ORGANISATIONS** 11

**VISITS BY INTERNATIONAL COLLABORATORS** 41

**INTERNATIONAL TRIPS MADE FOR RESEARCH COLLABORATION** 134

## NEW RESEARCH PARTNERS

In 2018, FLEET added three new partner organisations and five new Partner Investigators, expanding on existing research relationships and leveraging shared expertise. These new agreements bring FLEET's Australian and international partners to 16 (see chart below).


**Wroclaw University of Science and Technology (WUST)** is Poland's top-ranked new-technology university, excelling in computer science, electronics and material science. FLEET's new Partner Investigator Prof Grzegorz Sek, who specialises in nanophotonics, two-dimensional (2D) materials and exciton-polariton condensation, will work closely with FLEET CI Prof Ostrovskaya (ANU).

**The Beijing Computational Science Research Center (CSRC)** in China is a multidisciplinary, fundamental-research organisation undertaking computational science and condensed-matter research. FLEET's new Partner Investigator, CSRC Director Prof Hai-Qing Lin, coordinates collaborations with FLEET's Dr Dimi Culcer (UNSW), developing advanced new theoretical and computational techniques for studying topological phenomena.

**The University of Camerino** in Italy has had a dynamic and successful research partnership with FLEET researchers, now formalised via a partnership agreement. The University's Prof Andrea Perali and Prof David Neilson join FLEET as new Partner Investigators, studying the theory of exciton superfluids with FLEET CI Prof Alex Hamilton (UNSW) **(see exciton case study p30)**.

FLEET's fruitful relationship with **Tsinghua University** in Beijing, China, has expanded, with the Centre welcoming two new Partner Investigators to lead research collaborations. Prof Shuyun Zhou studies the electronic structure of novel 2D materials and heterostructures using advanced electron spectroscopic tools, and will work closely with Prof Michael Fuhrer (Monash University) on 2D deposition. Prof Pu Yu studies emergent phenomena at the interface of correlated electron systems and will work closely with Profs Xiaolin Wang (UOW) and Nagy Valanoor (UNSW) on ferroelectrics.

## EXPLORING POTENTIAL LINKAGES: NEW ZEALAND'S MACDIARMID INSTITUTE

In 2018, FLEET strengthened its links with leading New Zealand nanotechnologists via the **MacDiarmid Institute**, the country's leading nanotechnology and materials research organisation.

FLEET Director Prof Michael Fuhrer spoke at Materialise, the sustainable materials science event hosted by the Institute, introducing the NZ science community and media to issues around information and communication technology (ICT) energy use and ultra-low-energy electronics.

In return, five senior MacDiarmid researchers spoke at the FLEET annual workshop and at ICON-2DMat, introducing all FLEET members to leading nanotechnology and beyond-CMOS electronics research.


*FLEET Director Michael Fuhrer featured in an online game to engage the public with sustainable-materials science.*

*Scientific journal editorial panel, ICON-2DMat.*


## HOSTING INTERNATIONAL 2D MATERIALS CONFERENCE

FLEET hosted the International Conference on Two-Dimensional Materials and Technologies (ICON-2DMat) in Melbourne in December 2018.

This was the first time ICON-2DMat had been held in Australia, and with around 300 international and Australian delegates attending, it was an opportunity to showcase the strength of atomically-thin materials research in Australia.

Attendance at the international conferences on 2D materials is growing, reflecting rising interest in the useful electronic, opto-electronic and material properties of atomically-thin materials.

*FLEET Director Prof Michael Fuhrer.*


ICON-2DMat 2018 connected FLEET and other leading Australian 2D scientists with top international experts to discuss the latest research and emerging applications.

The international and Australian delegates enjoyed six plenary talks, 16 keynote talks, 148 oral presentations and over 90 poster presentations.

Free, on-site childcare was provided, paid for by the conference's sponsors and demonstrating FLEET's commitment to leadership in family-friendly conferences **(see p63)**.

**More information FLEET.org.au/ICON2DMAT**


*Recognising excellence, ECR poster sessions and networking, ICON-2DMat.*




*Research seminars present the latest science to relevant researchers, fostering valuable discussions and sparking future collaborations.*

> FLEET seminars have provided opportunities to share ideas with FLEET members, collaborators and industry figures from outside of our immediate research group.
>
> **Dr Karina Hudson**
> FLEET Research Fellow, UNSW


## HOSTING RESEARCH SEMINARS

In 2018 FLEET began a series of live-streamed seminars to help share research results across the Centre, keep members informed on latest FLEET research, and enhance inter-node collaboration. Early-career researchers presenting the seminars gain valuable presentation experience, and benefit from feedback on their research from diverse Centre members.

These seminars also provide an opportunity for regular get-togethers in each node, based around baked goods and coffees. Beginning in late 2018, FLEET live-streamed seminars have been presented by:

- Dr David Colas (University of Queensland)
- Dr Carlos Kuhn (Swinburne)
- Dr Mark Edmonds (Monash).

The 26 research seminars that FLEET hosted by visiting researchers at Monash and UNSW (see image to the left), exposed members and affiliates to diverse research from around the world. Visiting seminar researchers discovered shared approaches with FLEET and also discussed future collaborations, in some cases leading to formal partnerships, such a joint US grant, co-supervision of a PhD student, and two new Partner Investigators at Tsinghua University **(see New research partners, p54-55)**.

See FLEET.org.au/annual-reports for list of workshops and seminars

> FLEET has an increasingly visible presence in Australian science.
>
> **Prof Jared Cole**
> FLEET Chief Investigator, RMIT

# PROFESSIONAL COLLABORATIONS

In 2018, FLEET built on an existing strong relationship with the Australian Institute of Physics (AIP), the country's leading body for physics advocacy and support.

**With the AIP this year, the Centre:**

- Hosted a members' briefing and tour of FLEET labs at RMIT
- Ran two VicPhysics Girls in Physics breakfasts
- Assisted with Physics in the Pub in Melbourne and Brisbane
- Presented the annual AIP Nobel Lecture, given by Prof Kris Helmerson (Monash) who spoke on optical tweezers.

**FLEET continues to build links with other science organisations within Australia, for example:**

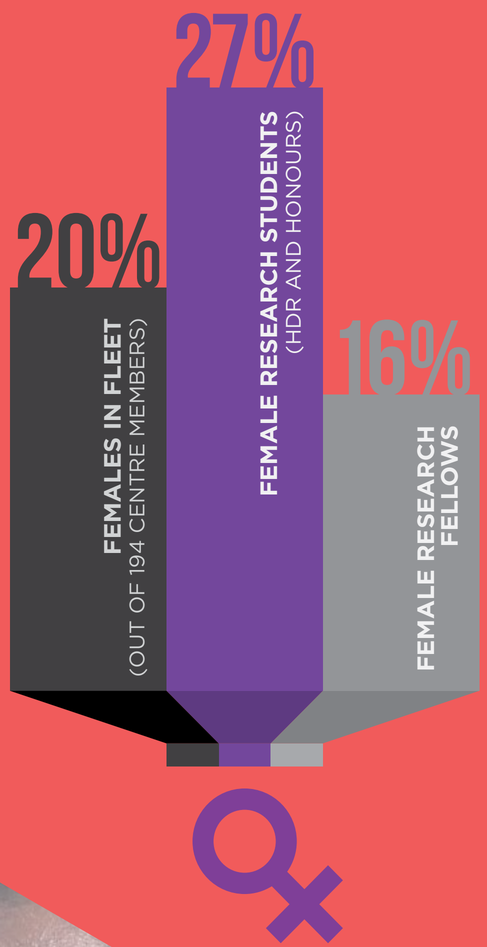
- Arranging co-sponsorship of the national science-communication conference by 11 ARC Centres of Excellence
- Participating in Victorian ARC Centres and Hubs workshop to share best practice and develop networks
- Working with the ARC Centre for Gravitational Waves (OzGrav) to develop a virtual reality outreach tool
- Operating lab tours with the Monash Tech School, introducing Year 8 students to science (see p75).


*Public events have provided valuable opportunities for collaborations with schools, professional bodies and other ARC Centres of Excellence.*

PhD student Vivasha Govinden and Research Fellow Dr Peggy Qi Zhang study ferroelectric materials at UNSW.

# 04 EQUITY

FLEET is breaking boundaries to improve gender-quity in science.





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

Our motivation is not only fairness. We also know that diverse teams do better science. By improving our performance with respect to gender-equity and diversity, we are not only doing what's right and fair, we will also be creating a more effective research team.

FLEET aims to achieve 30% women researchers across the Centre by 2021. In its second year, FLEET has exceeded the 2018 target of 15% women higher degree by research students (HDRs) and early-career researchers (ECRs), with 27% and 16%, respectively. This brings the current proportion of women across the Centre to 19%.

But this is just a starting point. In particular the Centre must increase the representation of women in more-senior roles.

FLEET's recruitment to date has drawn from the existing physics pool, which unfortunately has a relatively low percentage of women. FLEET's Women in FLEET Fellowships (see case study below) will allow the Centre to begin to increase the percentage of women at ECR level beyond 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.

## DID YOU KNOW...

*FLEET has people of 24 different nationalities and cultural backgrounds, across all levels of the Centre.*

## IN 2018, FLEET HAS:

- Targeted outreach to girls in schools to improve their future participation in science
- Analysed equity policies at all participating organisations to identify best practice
- Developed equity guidelines for all FLEET-supported events
- Identified internal cultural challenges via a comprehensive, Centre-wide survey (see below)
- Submitted recommendations to Australia's 'Women in STEM' Decadal Plan
- Continued to foster inclusive workplace practices such as part-time work, flexible hours and family-friendly meeting times.

## IN 2019, FLEET WILL:

- Create more career support opportunities for women at ECR level
- Implement straightforward feedback systems, for when exclusivity or discrimination occurs
- Improve cultural awareness and understanding of equity issues via seminars and training
- Make FLEET events even more friendly for parents of young children
- Create more mentoring opportunities for women and minority groups in FLEET
- Offer industry training, internships and mentoring opportunities for careers outside of academia.

More at FLEET.org.au/equity

## CULTURAL CHALLENGES AND MEMBERS' SURVEY

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

As a first step in this direction, in 2018 FLEET conducted a comprehensive cultural survey of members to determine attitudes to gender equity.

The anonymous, optional survey was answered by a third of members, and revealed that:

- Over 90% value equity and diversity
- Over 80% are aware of FLEET equity policies and initiatives
- Over 80% say their workplace is inclusive and respectful
- Over 70% participate in FLEET equity initiatives.

We found that discrimination and harassment are rare within the Centre and that, in most cases, complaints were resolved in an appropriate manner.

Negative attitudes to equity interventions have been documented across Australia, and FLEET has proven to be no exception. While the majority of members strongly support our equity measures, the survey also revealed some discomfort with initiatives created to support women in science, in particular with the Women in FLEET recruitment initiative.

An understanding of members' attitudes will allow FLEET to frame equity initiatives in a way that maximises the chances of success. We must ensure that all members understand what we are doing and why, and are empowered to speak up about difficulties.

> 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**
> Co-Director, MacDiarmid Institute NZ

## IN 2019, FLEET WILL:

- Assist members' understanding of their peers via cultural awareness training
- Educate FLEET members on equity and diversity issues using facts and high-quality studies
- Avoid demonising behaviours or resorting to emotional arguments, both of which prompt push-back
- Highlight benefits of diversity and of a family-friendly workplace to all employees
- Encourage men to be champions of change, reducing the 'burden of expectations' on their female colleagues
- Keep listening.

*Welcoming families to the FLEET Annual Workshop.*


## SHIFTING THE DIAL: WOMEN IN FLEET FELLOWSHIPS

FLEET's recruitment to date has drawn from the existing physics pool, which (along with related fields such as engineering and material science) unfortunately features a relatively low percentage of women.

Women in FLEET Fellowships will allow the Centre to begin to increase the percentage of women above the average in these fields.

The Fellowships also allow for improved flexibility in the location and type of position on offer. FLEET's previous recruitments have been highly-focused research roles with specific expertise criteria, which has resulted in maintaining 'status quo' in gender balance.

The new Fellowships target early-career researchers who identify as female and have research interests aligning with any research areas within FLEET, giving applicants the choice to nominate investigators they want to work with. This broader search will allow FLEET

> The logistical complexity of the recruitment process across all FLEET nodes was a huge challenge, but it was exciting to do something radically new in the area of gender equity.
>
> **Elena Ostrovskaya**
> Chair, FLEET Equity and Diversity Committee

to find excellent researchers who may have been missed in previous, narrowly-targeted searches.

Although it sounds simple, these Fellowships faced significant challenges in order to work with equity and recruiting policies across all FLEET member universities.

The end result has been two Women in FLEET Fellowships being offered for appointment in early 2019. Our first two Women in FLEET Fellows could be experimental or theoretical, and physicists, chemists or engineers, located at any of five universities. The flexibility of offering whichever field suits the best applicants available allows the widest choice of applicants, ensuring we will hire the best possible candidates.

FLEET received almost 70 applications and is currently interviewing candidates. A very large selection committee (seven members) for a Research Fellow position ensures representation across all FLEET themes and nodes.

## FAMILY FRIENDLY WORKSHOPS AND CONFERENCES

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.

At FLEET's annual workshops **(see p86)**, families and partners are welcomed to all meals and social events, and the Centre provided free on-site childcare for all delegates.

Free on-site childcare was also provided at the international conference ICON-2DMat hosted by FLEET in 2018 **(see p56)**. Between the two events, 26 children were cared for, allowing their parents to participate fully in lectures and seminars.

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 39 partners and family members.

As well as ensuring that FLEET's own events are family-friendly and supportive of diversity, the Centre has decided that events hosted or sponsored by the Centre must be similarly supportive. To that end, FLEET has set equity guidelines for all supported events: FLEET will only fund events that consider equity and diversity in their speaker selection, family-friendly policies and assistance, and overall event organisation. See the Equity & Diversity Committee **(p96)**.

> The family-friendly environment at FLEET's annual workshop was unprecedented – I've not seen this at any other scientific meetings.
>
> **Luigi Colombo,**
> FLEET Advisory Committee

# 05 EDUCATION

*Training early-career researchers at FLEET annual workshop.*

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

RESEARCH WORKSHOPS AND CONFERENCES ORGANISED

**12**

RESEARCH SEMINARS HELD

**26**

FLEET-WIDE, LIVE-STREAMED SEMINARS

**3**

RESEARCH AND PROFESSIONAL DEVELOPMENT WORKSHOPS

**7**

OUTREACH ACTIVITIES INVOLVING FLEET MEMBERS

**132**

MENTORING PROGRAMS

**4**

> FLEET provides me with access to a broad network with diverse scientific know-how, from fundamental research all the way to devices and applications.
>
> **Dr Agustin Schiffrin**
> FLEET Chief Investigator, Monash

## BUILDING FUTURE SCIENCE LEADERS: EDUCATION AT FLEET

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

The Centre currently supports 42 higher degree by research (HDR) students and 49 early-career researchers (ECRs), with another 22 research affiliates working on FLEET projects and invited to Centre training, workshops and events.

All FLEET's students and young researchers receive excellent supervision, are exposed to opportunities for professional development and networking, and are supported in navigating diverse career pathways.

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


## YouRforum

**So you've got a PhD, now what's next?**

Because most PhD graduates will not end up in academia, FLEET assists HDRs in developing a diverse skills base to maximise future career opportunities.

In 2018, FLEET's **YouRforum** (Young Researchers Forum) was expanded to UNSW, where a panel of science PhDs discussed career options for STEM PhD graduates and ECRs. Participants heard from nine academics, entrepreneurs, business development and research managers, who shared their career journeys and top tips on making the most of a PhD. **YouRforum** was an original initiative of the Monash Centre for Atomically Thin Materials.

*Developing future skills, YouRforum early-career development training and panel, UNSW.*

### HIGHLIGHTS IN 2018

- Launching FLEET's mentoring programs
- Joining with the ARC Centre for Engineered Quantum Systems (EQUS) to run the Idea Factory **(see case study p67)**
- Starting monthly FLEET-wide live-streamed seminars
- Contributing to the ANU summer school on topological physics **(see p68)**
- Hosting *Nature*-paper writing workshop, at the FLEET annual workshop.

### IN 2019, FLEET WILL:

- Improve ECRs' entrepreneurship and commercial skills
- Provide gender-equity and diversity training
- Provide opportunities for HDR students to visit other nodes' labs
- Continue building members' communication skills **(see p82)**
- Grow and monitor FLEET's mentoring program
- Assist with the Canberra International Physics Summer School at ANU in January 2020
- Launch an internal FLEET grant program for ECRs aimed at developing new collaborations
- Launch Women in FLEET mentoring program.

## FOSTERING HELPFUL RELATIONSHIPS: MENTORING AT FLEET

FLEET recognises that, no matter where they are in their career, many of our members would benefit from a mentor to help prepare them to take 'the next step'.

A mentor provides independent, thoughtful support and a sympathetic sounding board, and can help with practical or people issues, or in career planning.

2018 saw FLEET launch its mentoring programs, focusing on three different sectors: industry, academic and early-career researchers.

Thirty FLEET members have been matched with mentors, making connections both within the Centre and externally. The FLEET annual workshop provided an opportunity for a face-to-face meeting for many mentor–mentee pairs, and a number of useful collaborations have already come out of these relationships.

The program is flexible, covering mentoring relationships that are general and ongoing, as well as short-term arrangements targeted at a specific outcome – for example, obtaining a grant or getting promoted.

Learning works both ways in a good mentor–mentee relationship, and a number of FLEET members are building their own mentoring experience via mentees from outside the Centre.

> 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

## PITCH PERFECT: THE IDEA FACTORY

FLEET has begun an ongoing partnership with the ARC Centre for Engineered Quantum Systems (EQUS) to run a yearly ECR workshop building skills in communication, methods for pitching and presenting science, and working collaboratively with others.

In between the teams' pitch preparation and delivery, formal training sessions included science communication, oral presentations and how to craft an engaging research pitch.

The Idea Factory challenged small, diverse teams of ECRs to develop and pitch a research proposal to a panel of judges.

The ability to explain a proposal's significance and innovation to a technically-competent but broad audience is a key skill for ECRs.

> The Idea Factory taught me to pitch a project quickly and with impact (much more difficult than it sounds!) and to explain why I was 'the right person for the job' (a challenge, as we don't feel comfortable bragging).
>
> **Dr Antonija Grubisic-Cabo**
> FLEET research affiliate, Monash

As well as developing these pitching and communication skills, the workshop focuses on collaboration. Each teams' mix of institutions and research areas, including theorists and experimentalists, gives participants additional challenge, and value. The ability to collaborate across traditional boundaries is key for future careers.

The Idea Factory develops necessary skills for a research career, whether in industry or academia, or wherever the future lies.

The Idea Factory is one of several successful collaborations with other ARC Centres run this year **(see p59)**.

CASE STUDY

## NETWORKING AND SKILLS DEVELOPMENT: TOPOLOGICAL SUMMER SCHOOL

Recognising the increasing importance of topological physics, FLEET helped run the 2018 Canberra International Physics Summer School on Topological Matter at ANU – a great opportunity for early-career Australian physicists to hear from leading experts from around the world.

Over 90 attendees discovered topological materials' applications to photonics, ultra-cold systems and quantum computation.

Nobel laureate Prof Duncan Haldane (Princeton University) was the headline presenter, describing the study of topological materials that saw him named co-recipient of the 2016 Nobel Prize in Physics.

FLEET's Elena Ostrovskaya (ANU) and Jeff Davis (Swinburne University) helped organise the summer school and a number of senior FLEET members gave presentations. FLEET also provided communications and marketing assistance.

Co-sponsorship by the US Embassy in Canberra introduced an element of international cooperation, and public events included a talk by Prof Haldane, a topologically-themed Physics in the Pub event, and media coverage.

> The Topological School was fantastic, with a broad spectrum of lectures. A number of students commented on how much they had learned.
>
> **FLEET PI Prof Victor Galitski**
> University of Maryland

FLEET will continue to leverage the established ANU Summer School platform, aligning topics to FLEET research approximately every two years. This will introduce a wider scientific community to FLEET-related science and give ECRs an opportunity to build their knowledge base.

The 2020 physics summer school will cover spontaneous quantum coherence.

### OTHER TRAINING PROGRAMS RUN BY FLEET THIS YEAR INCLUDED:

- **Outreach training** (Melbourne and Sydney)
- **Thin-film X-ray diffraction (XRD)** skills refresher, run by FLEET Research Fellow Dr Dan Sando (UNSW)
- **Tall Poppy training** with Education Liaison Camille Thomson (held at Monash University)
- **Ferroelectrics workshop** run by FLEET Research Fellows Dr Dan Sando and Dr Peggy Zhang (UNSW)
- ***Nature* paper and pitch training** at the FLEET annual workshop (see p86)
- **YouRforum Post-PhD development training** (UNSW).


*Left: ECRs meet Nobel laureate Duncan Haldane at Topological Matter School (ANU).*

*Right: Education Liaison Camille Thomson.*

## BUILDING MEMBERS' OUTREACH SKILLS: MELBOURNE KNOWLEDGE WEEK

Melbourne Knowledge Week (May 2018) was an opportunity for FLEET to engage with the public and road-test a number of outreach demonstrations being developed for schools. It also gave 20 Centre members the opportunity to gain valuable experience in public science outreach, speaking to a diverse audience.

Melbourne Knowledge Week showcases cool science and engineering projects in the city of Melbourne, connecting non-scientists with the research and technology around them.

FLEET's Novel Electronics presentation ran for the full week at the festival hub, with hands-on science demonstrations linked to materials used in FLEET research, such as gallium, bismuth and ferrofluids.

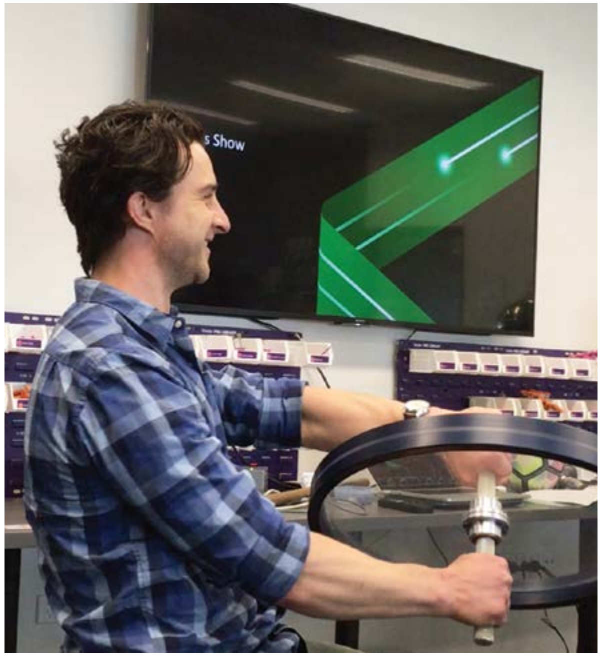
FLEET members staffed the stand in small teams to demonstrate electrical and magnetism concepts, operate (and constantly tweak!) the laser maze, and explain FLEET's research.

This year FLEET has focused on improving members' skills and confidence in public engagement, and other forms of science communication **(see more on p82)**.

FLEET will be participating in Melbourne Knowledge Week 2019 with new activities under development.


> Melbourne Knowledge Week was a highlight for me in 2018, as was helping a primary school science teacher at Surrey Hills Primary School and volunteering for a Scienceworks excursion for Primary School students and kindergarten students.
>
> **Dr Shilpa Sanwlani**
> FLEET Research Fellow
> Swinburne

*FLEET members gained valuable science-outreach experience by participating at public events, as well as via dedicated Centre outreach training.*



*Secondary-school students experiment with magnetism, one of several school demonstrations at FLEET's official launch.*

# 06 ENGAGE

FLEET is engaging Australians with science — from school to public to policy makers.

**1572**

AVERAGE MONTHLY **NEW USER VISITS TO FLEET.ORG.AU**

**5644**

AVERAGE MONTHLY **UNIQUE PAGE VIEWS**

**2318**

VIEWS OF **FLEET RESEARCH VIDEO**

(1768 new views)

**413**

**FACEBOOK** FOLLOWERS

(196 new followers)

**594**

**TWITTER** FOLLOWERS

(310 new followers)

**47** **HOME SCIENCE ACTIVITIES** DEMONSTRATED

**1551** HOURS SPENT ON **OUTREACH**

**197** **SCHOOL TEACHERS** ENGAGED

**676** TOTAL NUMBER OF CENTRE MEMBERS ATTENDING **TRAINING WORKSHOPS**

**1130** TOTAL NUMBER OF NON-CENTRE MEMBERS ATTENDING **TRAINING WORKSHOPS**

**11,186** PUBLIC AUDIENCE REACHED THROUGH **OUTREACH ACTIVITIES**

**2189** SCHOOL STUDENTS REACHED THROUGH **OUTREACH ACTIVITIES**

**22** PRESS RELEASES

**6** PRINT ARTICLES

**7** NON-PEER REVIEWED ARTICLES

**2** MENTIONS ON TELEVISION

**8** RADIO INTERVIEWS

**197** MENTIONS IN ONLINE MEDIA

*Secondary-school students experiment with magnetic properties of bismuth, one of the 'toolkit' of school activities developed for school outreach.*

# 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.

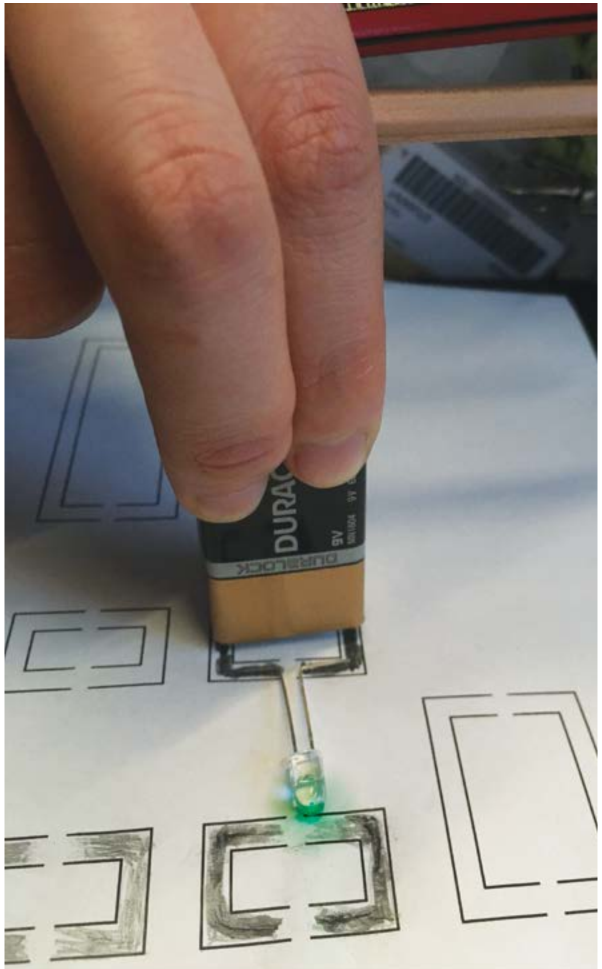
**See p59** for successful outreach collaborations in 2018, including development of a virtual reality tour of FLEET labs, and significant outreach collaborations with the Australian Institute of Physics.

In 2019, FLEET will launch 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 will also be Australia's first introduction to superfluids and topological materials at the secondary school level.

See the Outreach Committee on **p98**.

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

> FLEET is to be congratulated on its outreach activities. Requiring each Centre member to spend 20 hours per year on outreach also provides significant benefits in the training and development of Centre researchers.
>
> **FLEET Advisory Committee**



Demonstrating electrical conduction in graphite.
And using molecular models to describe 2D materials.

## 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.**


*FLEET members hosted over 600 students on tours to Centre labs and visited nine schools.*

> FLEET's partnership with Monash Tech School has given students a new perspective on the importance of research. Being able to see scientists at work in state-of-the-art facilities, and having the chance to ask researchers questions, is unforgettable.
>
> **Neil Carmona-Vickery**
> Deputy Director,
> Monash Tech School

> Communicating learnings associated with FLEET into schools will be essential as we continue to use more technology in our everyday lives.
>
> **Andrew Chisholm**
> Assistant Principal,
> John Monash Science School

*Schools outreach also gives FLEET ECRs valuable opportunities to develop their science-communication skills.*

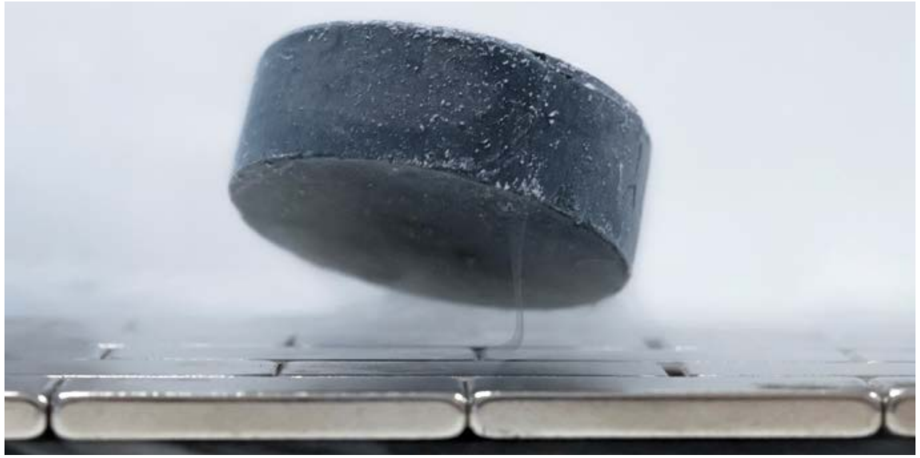

## ENGAGING SCHOOL STUDENTS

Over the course of 2018, 16 FLEET members visited or hosted 22 schools, engaging students with relevant issues such as information and technology (ICT) energy use, how transistors work and the new fields of science studied at FLEET.

Our visiting scientists were kitted out with an outreach toolkit developed in-house, including mechanical digi-computers to demonstrate binary operations, two-dimensional (2D) material demonstrations, an electronics card game and virtual reality viewers.

FLEET hosted lab tours in a very fruitful partnership with the new Monash Tech School, which provides hands-on science experiences for participating secondary students. During 2018, over 200 teachers and students from 10 schools were shown through FLEET labs by young Centre researchers.

Targeting students from remote schools, who do not get the opportunity to visit urban universities, FLEET also collaborated with others to create a virtual tour of FLEET labs **(see p59).**



*A super-cooled, superconducting 'puck' floats around a magnetic track. FLEET's Mobius track has proven extremely successful at engaging school students with science.*

## SUPERCOOL, SUPERCONDUCTING FLEET MOBIUS TRACK

FLEET's superconducting track features 1500 neodymium magnets, fixed into the shape of a Mobius strip, so that a small superconducting 'puck', when cooled in liquid nitrogen, will whizz around the track, spending half of each orbit hanging suspended upside down.

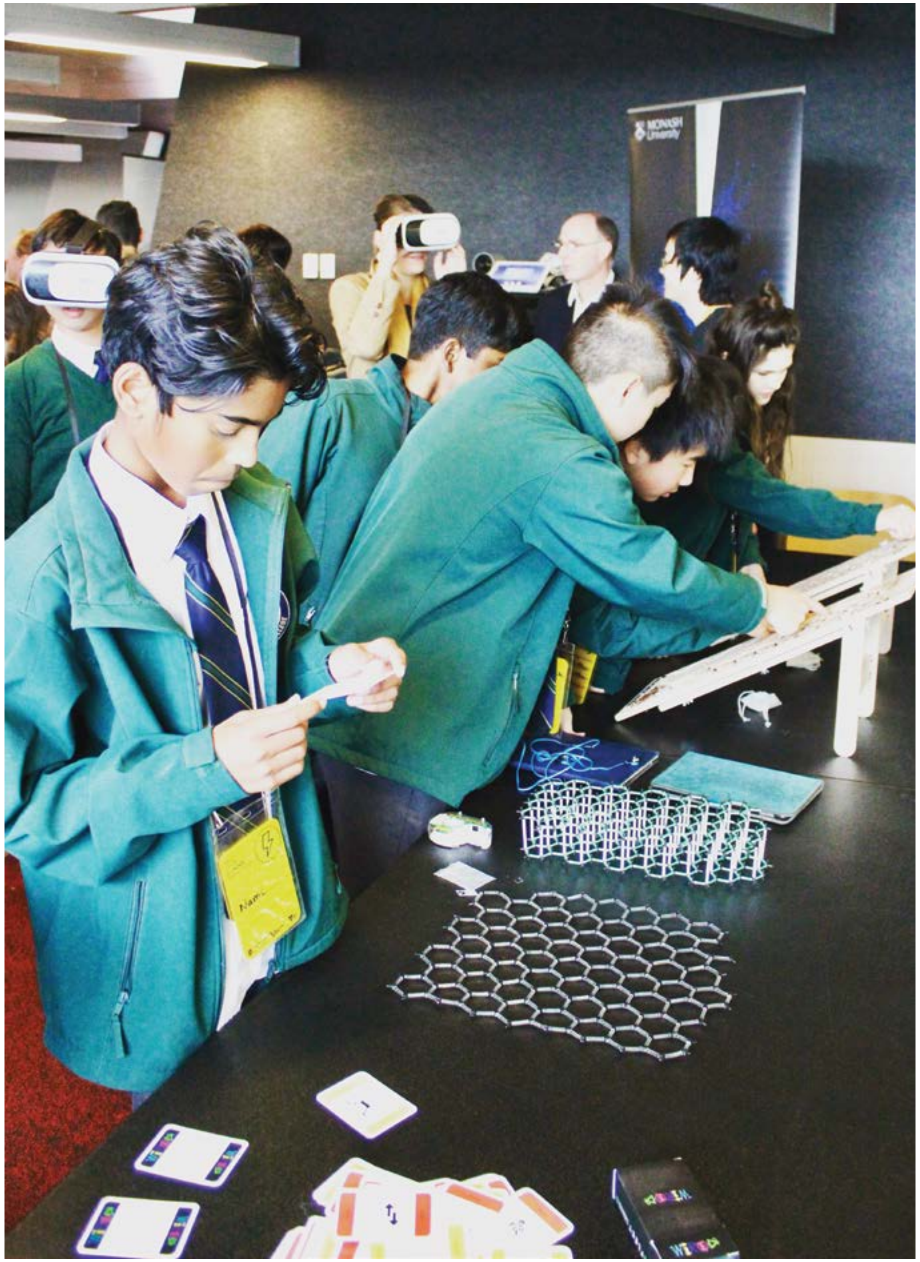
The track allows FLEET to demonstrate several relevant science concepts, including:

- Topology (via the Mobius strip – incidentally, mirroring the shape of FLEET's logo)
- Superconductivity (an interesting quantum state with implications for electric current)
- Magnetism
- Low-temperature physics
- Demonstration of invisible, atomic-scale science, via a physical demonstration.

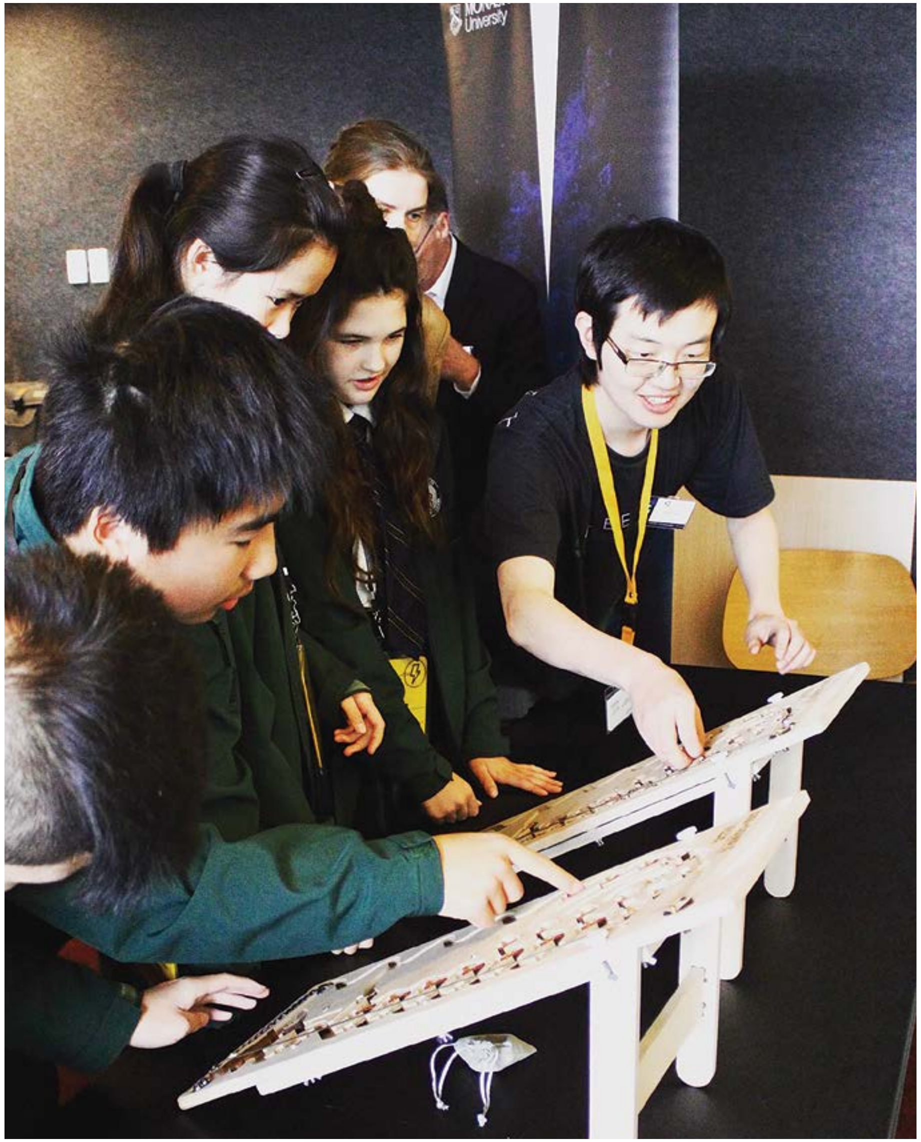
And it's also really fun, which is the key: physical science demonstrations that make a strong impact have a clear advantage in embedding learnings. The Mobius track and associated liquid nitrogen have been a highlight of lab tours and open days at Monash University and UNSW – no matter the age group, from school students to visiting scientists.

FLEET's prototype Mobius track was built by Monash University undergraduates as a summer research project, in collaboration with the Faculty of Science (the prototype is now used at Melbourne's Scienceworks museum). Subsequent, fine-tuned Mobius tracks are now used as outreach tools by FLEET teams at Monash and UNSW.

**See more at FLEET.org.au/mobius**




*Secondary-school students experiment with FLEET virtual reality (VR) lab tours, atomic models and manual digital computers.*




*Dr Daisy Wang (UNSW) speaking at the FLEET launch.*

*Future's so bright... laser lab tour during FLEET launch.*

## LAUNCHING THE FLEET

FLEET's official launch in June 2018 was an opportunity to tell the story of FLEET to around 150 researchers, policymakers, stakeholders and school students.

The Centre's launch successfully incorporated diverse voices, from multiple FLEET nodes, and fully engaged all seven universities' communication teams. Invitees ranged from policymakers and university and partner stakeholders and affiliates to FLEET members from across the country, and a contingent of school students.

The event showcased the Centre's school science outreach efforts in spreading a passion for science to Australian schools, with an enthusiastic group of high-school students from Mount Waverley Secondary College 'road-testing' FLEET's suite of hands-on science demonstrations.

The audience heard from a range of speakers of various experience levels, including representatives from four of the Centre's seven Australian research nodes, speaking on FLEET's mission of addressing the challenge of ICT energy use, FLEET science, and Centre strategies to make an impact 'beyond the science' (that is, in member development and public outreach).

FLEET took advantage of the rare opportunity of having all its staff together to hold a short research workshop, sharing progress to date and fine-tuning research direction.

**See more at FLEET.org.au/launch**

*Mobius demonstration.*

*Prof Jared Cole (RMIT).*

*Prof Matt Davis (UQ).*

*MC Prof Ana Deletic (UNSW).*

*Prof Sue Thomas (ARC).*

## SHARING FLEET RESEARCH: COMMUNICATION

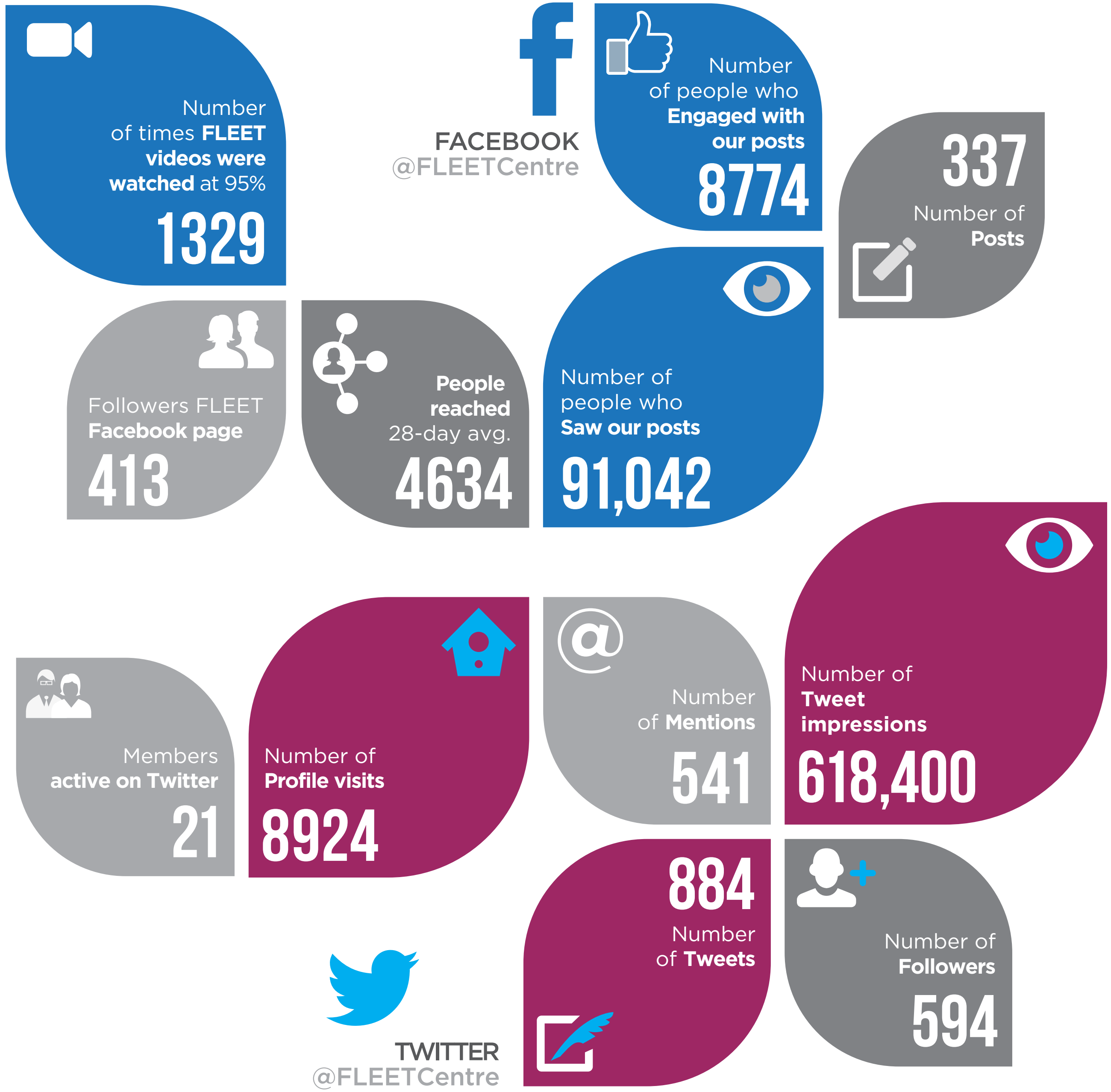
FLEET's communications functions include:

- 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.

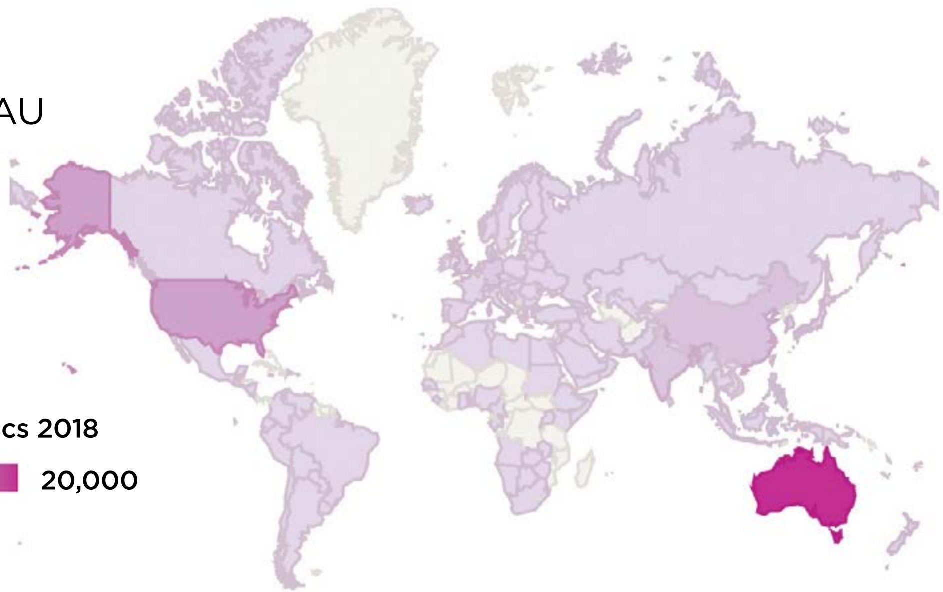
In 2018, FLEET used its official launch to showcase the Centre's story **(see case study p78)** and to engage key stakeholders. We expanded our reach to stakeholders via social media and a newsletter. And we began to develop our members' own communications skills.

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 (exceeding the media mentions KPI by a factor of five).

See the Communication Committee on **p100**.



## FLEET.ORG.AU



**Website statistics 2018**

1 – 20,000

Number of **Unique page views** 67,800

Number of **New users** 18,500

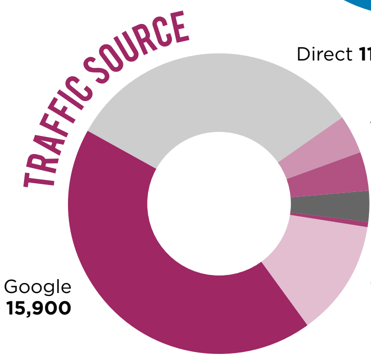
Number of **Pages per session** 2.4

Number of **Sessions** 35,950

Number of **Pages visits** 790

LINKEDIN

Number of **Post views** 18,524




> I am able to stay in touch with what's happening around FLEET via the members newsletter, the FLEET.org.au website, and via social media.

**James Collins**
FLEET PhD student,
Monash

> A strength of FLEET's is the communication between different groups, such as our RMIT/UNSW collaboration this year.

**Cheng Tan**
FLEET PhD student,
RMIT

*Research Fellow Carlos Noschang Kuhn (Swinburne) demonstrates scientific principles with water-powered rockets.*

## DEVELOPING FLEET MEMBERS' OUTREACH AND COMMUNICATION SKILLS

FLEET is equipping and empowering our members to communicate their own scientific work.

The Centre provides training, support, incentives and opportunities for members to develop their science communication and public speaking skills, setting them up for future success in research or other fields.

This has the additional benefit of exposing students and public to genuine, young, relatable operating scientists, and is particularly important in making girls aware that science is not just for boys.

In addition, having the researchers themselves telling the story of their own research results in science communication that is more authentic and more compelling.

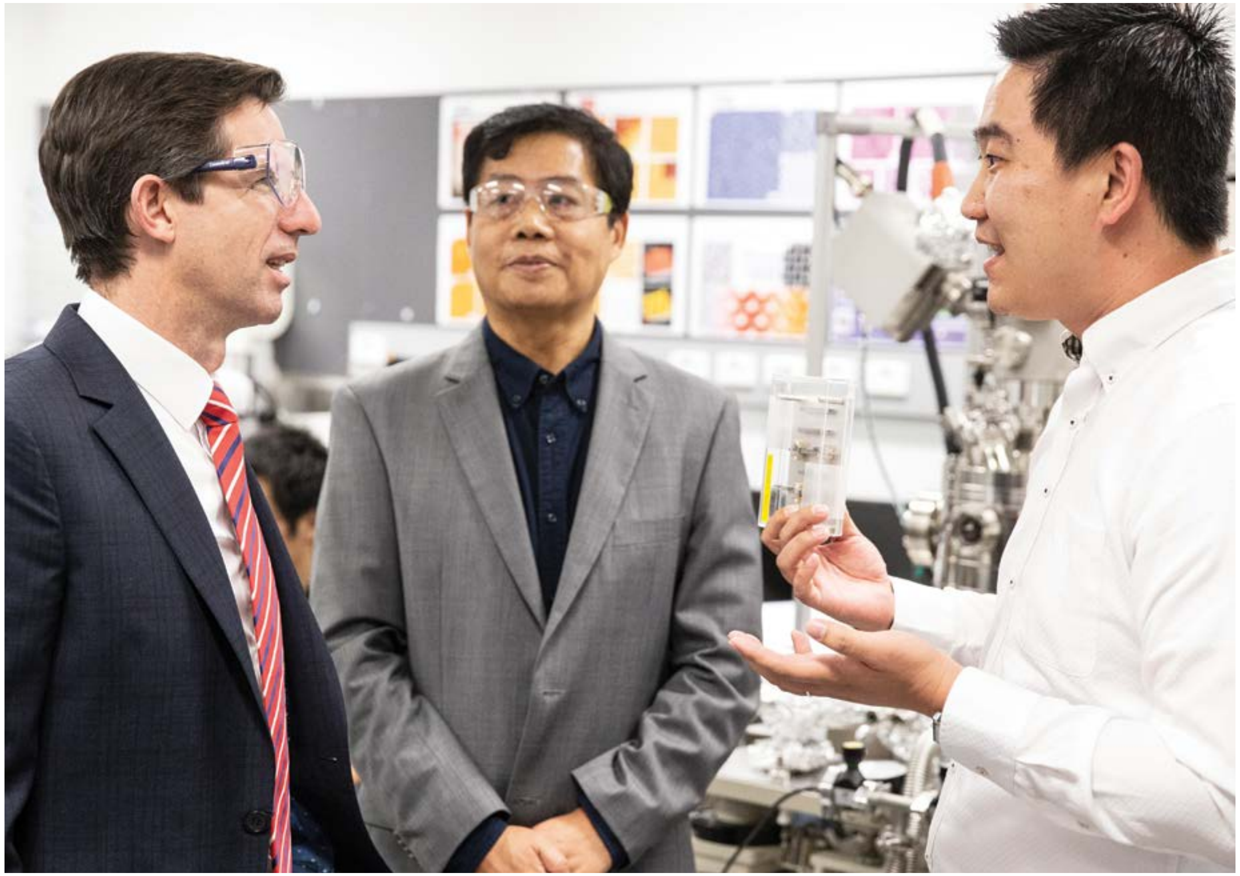
Many FLEET members achieved the Centre's goal of a minimum of 20 hours of outreach per year, with one scientist achieving over 50 hours. Next year, the Centre will provide even more opportunities, in particular further support for those members who have found outreach most challenging.

FLEET PhD student Rebecca Orrell-Trigg (RMIT/UNSW), excelled in her first ever radio interview, discussing her research project on Radio RRR science show Einstein a Gogo.


> Engaging with public and students has been a personal highlight in 2018. At Monash University Open Day I got to explain FLEET's focus and relevance to the general public, and describe my job as a researcher to many potential future physics students.
>
> **Dr Changxi Zheng**
> FLEET Research Fellow,
> Monash University

**Communications development activities of our members in 2018 included:**

- Outreach at schools, hosting lab tours, presenting FLEET science at university open days at all seven FLEET nodes
- *Nature*-article writing workshop at FLEET's annual workshop **(see p86)**, and panel of journal editors at ICON-2DMat **(see p56)**
- Members' articles published in *Australian Physics* and *The Conversation*
- Eight radio interviews, including early-career researchers and PhDs
- Onstage presentations including Pint of Science (Wollongong), Physics in the Pub (Melbourne and Brisbane), and the Great Science Debate (Melbourne and Sydney)
- Early-career representation at FLEET launch
- Outreach training in Sydney and Melbourne
- Melbourne Knowledge Week **(see case study p69)**.



## ENGAGING WITH POLICYMAKERS

Education Minister Simon Birmingham and ARC CEO Sue Thomas visited FLEET labs at the University of Wollongong's (UOW's) Innovation Campus. UOW node leader Prof Xiaolin Wang, Centre Deputy Director Prof Alex Hamilton (UNSW) and UOW researchers gave the Minister a quick introduction to ICT energy-use issues, topological insulators and atomically-thin materials, including a tour of labs where novel materials are developed within FLEET's Enabling technology A.

Melbourne MP and Greens Science and Energy spokesperson Dr Adam Bandt visited FLEET's labs at RMIT, meeting members and learning about the ICT energy-use issues that underlie FLEET's mission.

Host Prof Kourosh Kalantar-zadeh also introduced Dr Bandt to the members of ARC Centres for Quantum Science and Exciton Science; the three ARC Centres' co-location at RMIT Research provides valuable crossovers of ideas.

*Introducing policymakers to FLEET science: Greens science spokesperson Dr Adam Bandt at RMIT (right and upper left) and Education Minister Sen Simon Birmingham at UOW.*

# ENGAGING WITH INDUSTRY

FLEET will present the electronics industry with viable technical solutions to the problem of power consumption at data centres, producing more-efficient electronic circuits and memory devices.

In 2019, FLEET will:

- Produce electronic materials intellectual property that can form the basis of spin-off companies
- Build links to intermediary research institutes and provide an avenue to deliver intellectual property to development laboratories with a commercialisation focus
- Leverage strong ties with research centres focused on novel materials research and translation; for example, the Monash Centre for Atomically Thin Materials
- Liaise with potential stakeholders in novel electronic devices and systems through an industry network.

2018 highlights

- Formed collaborative research grant opportunities with Lockheed Martin, Merck Australia and Invest Shenzhen, China
- Explored future research collaborations with AMNY Medical, Advanced Functional Materials and Solar Energy Association Shandong, China and the MacDiarmid Institute **(see p55)**
- Explored potential funding opportunities with investment brokers
- Established contacts with potential collaborators and end users Minetek Sydney and GoogleX.

See the Industry Relationship Committee **(p99)**.

Also see new partnerships **(p54)**.


# BUILDING A COHESIVE CENTRE: FLEET'S ANNUAL WORKSHOP

**Forging a Centre that is greater than the sum of its parts**

FLEET's second annual workshop built on the successes of the 2017 workshop, bringing all of the Centre's members and many international partners together in Magenta, mid-coast New South Wales.

As in 2017, the workshop was family friendly, with partners and family made welcome at shared meals, social events and poster sessions, and with free, on-site childcare on offer to those with young kids. Almost 40 partners and other family members took us up on this offer, and care was provided for 16 children.

Other highlights included:

- How to write and pitch a *Nature* paper: a development workshop for early-career researchers
- Inaugural FLEET trivia night
- Talks by a wealth of visiting international collaborators and partners
- Industry engagement panel
- Video presentation by CSIRO Chief Scientist Cathy Foley.

*Sharing research results with colleagues from other nodes and research streams via poster sessions at the FLEET Annual Workshop.*

FLEET's 2nd Annual Workshop strengthened links between nodes and themes.

In my short career, I have never enjoyed a conference as much as FLEET's second annual workshop, both socially and scientifically. It is a huge credit to everybody involved in its organisation, and the spirit of the centre as a whole.

**Dr Jackson Smith**
FLEET Research Fellow, RMIT

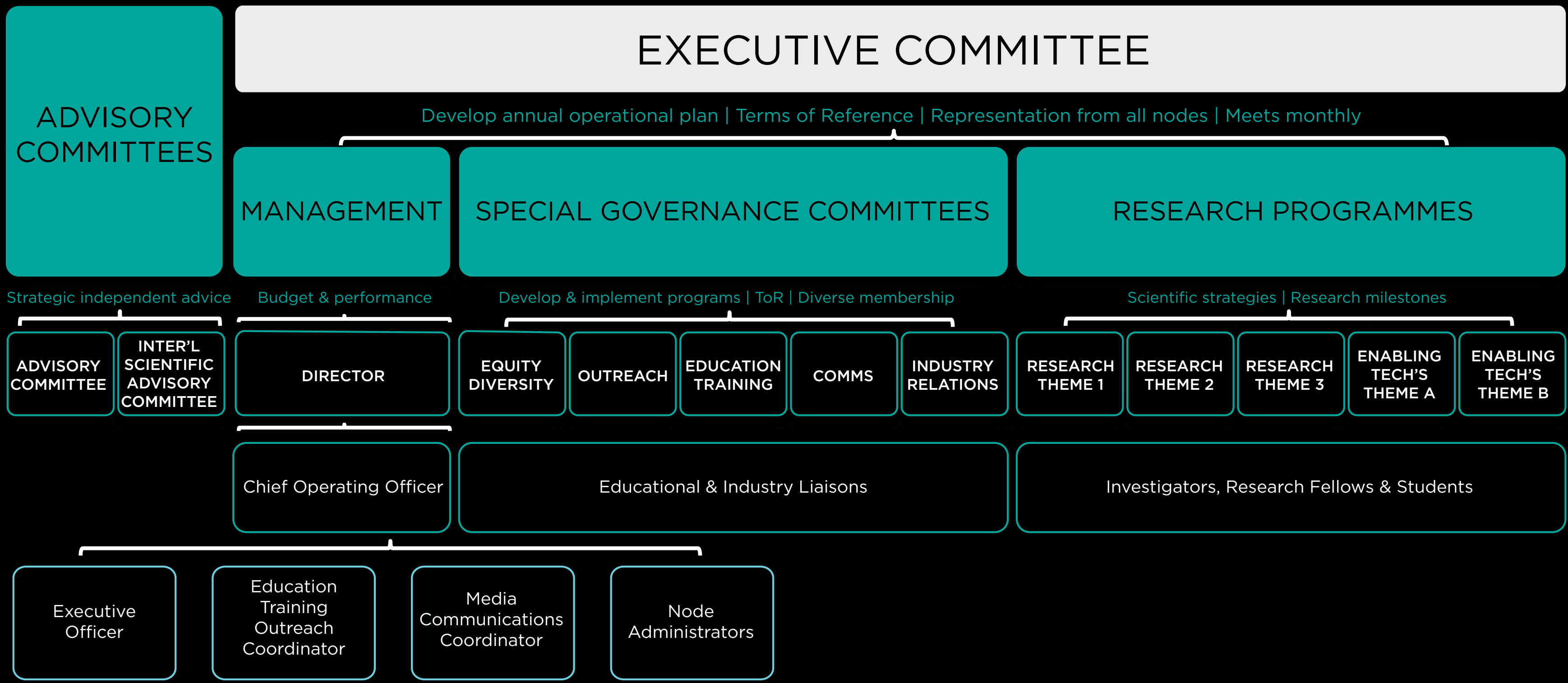
The poster sessions at FLEET's annual workshop were extremely valuable, giving me the opportunity to interact directly with the researchers.

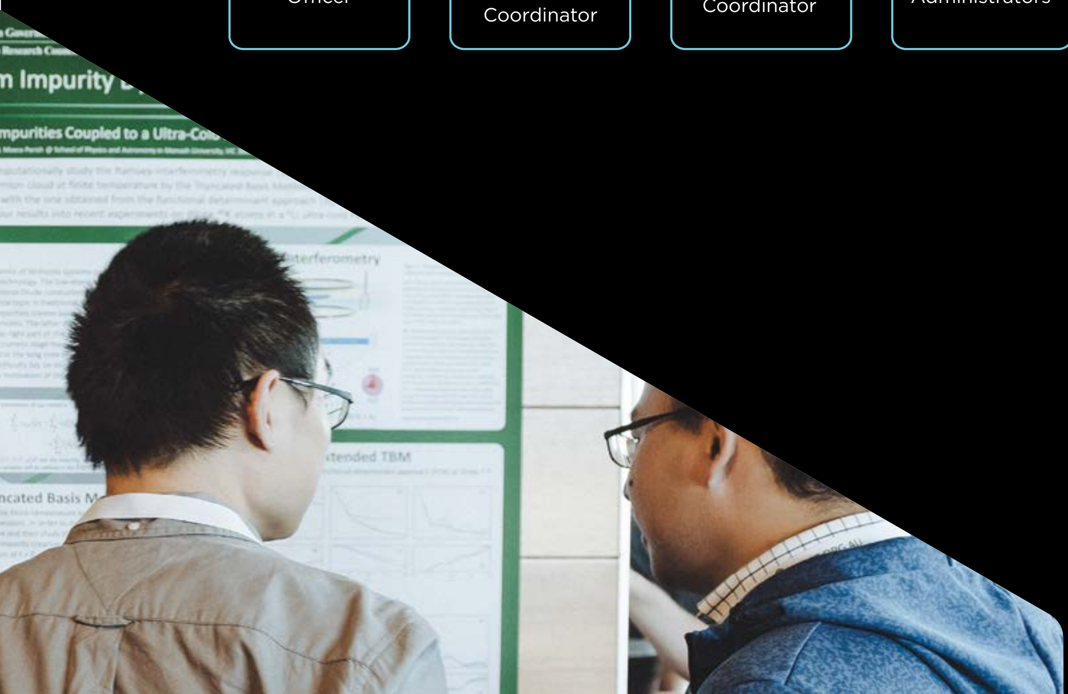
**Dr Ian Spielman**
FLEET Partner Investigator, University of Maryland

# 07 INSIDE FLEET


*FLEET Research Fellows Shaun Johnston (Monash) and Shilpa Sanwlani (Swinburne) discuss their shared research of ultracold non-equilibrium systems.*

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


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



DR CATHERINE BUCHANAN

**Executive Officer**

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

CECILIA BLOISE

**Node Coordinator UNSW**

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

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.

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.

KATHLEEN HICKS

**Node Administrator ANU**

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

NICCI COAD

**Node Administrator RMIT**

Nicci coordinates reporting of KPIs and budgets and provides administrative support to node leader Prof Lan Wang and the RMIT team.

TATIANA TCHERNOVA

**Node Administrator Swinburne**

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

DR TICH-LAM NGUYEN

**Chief Operating Officer**

Tich-Lam oversees FLEET's financial and operational effectiveness. She leads the Centre business team and drives strategic focus and the achievement of key FLEET goals.

"FLEET provides great logistical and administrative support, for example coordinating Centre efforts in training, mentoring, media and communications."

**Dr Agustin Schiffrin**
FLEET Chief Investigator,
Monash University

"FLEET is doing very well with research, education, collaboration, and promotion of underrepresented minorities. It's very encouraging to see high quality publications by Centre researchers and the active participation of students and post-docs."

**Dr An Chen**
FLEET Advisory Committee
IBM

## ADVISORY COMMITTEE (AC)

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

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

After meeting at Magenta (NSW), the FLEET Advisory Committee (AC) has reported on Centre activities:

The Advisory Committee is impressed with the performance and achievements of FLEET to date. The scientific themes and approaches within FLEET are well structured and the Centre is showing signs of strong scientific results, with some high-impact publications.

The Centre should strengthen its industry engagement activities. FLEET offers enormous potential but there is a danger that FLEET researchers may perceive themselves as being removed from industry interactions. The experience of successful translators of cutting-edge research is that it is never too early.

FLEET's strategic plan is rational and detailed and adequately quantifies measurables. In some cases, typically where KPIs are not being met, the AC advised the FLEET Executive to formulate plans to meet the targets.

Overall, the committee is impressed by a sound management structure designed to encourage scientific productivity in an inclusive way from a diversity of members. In particular, the AC notes that FLEET is providing excellent support for families and junior researchers.

**Full report available at FLEET.org.au/advisory-report**

## INTERNATIONAL SCIENTIFIC ADVISORY COMMITTEE (ISAC):

- Provides independent scientific advice to FLEET investigators, both directly and through the Centre Director
- 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.

> It is an exciting time for the study of topological phases of matter, and it is great to see FLEET's focus on using this new science for more efficient electronics.
>
> **Prof Ali Yazdani**
> *Princeton Center for Complex Materials*
> FLEET International Scientific Advisory Committee

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

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

| | 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:<br>• participating members<br>• external mentors<br>• research/professional development courses<br>• mentoring programs<br>• 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:<br>• travel grants facilitating collaboration<br>• FLEET-wide colloquia, research seminars and workshops<br>• collaborative visits by FLEET partners<br>• intra-Centre expertise exchanges<br>• 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:<br>• investigators/ECRs/students visiting partner organisations<br>• 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:<br>• relationships with end-users<br>• 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<br>High levels of satisfaction with FLEET workplace culture<br>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<br>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<br>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<br>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:<br>• social media audience reached on priority channels (Twitter, Facebook)<br>• 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:<br>• non-peer reviewed articles<br>• members discussing their science on social media<br>• members presenting their research in a public forum<br>• student members participating in Three-Minute-Thesis competition, and similar |

# FLEET'S 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
- Proper allocation of funding
- Approval of Centre activities
- Approval of Centre intellectual property ownership
- Approval of any amendments to 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 of the study of electronic properties of 2D materials, with extensive experience establishing and managing large, interdisciplinary research teams in Australia and the USA.

He 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 regarding 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 an ARC Laureate Fellow and 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's 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.

> Working with the central FLEET ops team is a treat. I never feel isolated as a node administrator, because of the team spirit, availability, and disposition of the central team. Great team, top culture – one of the best I have worked with.
>
> **Cecilia Bloise**
> *Node administrator, UNSW*

## COMMITTEE MEMBERS:

PROF ALEX HAMILTON
**Deputy Director**
**Leader, Research theme 1**
Node leader, University of New South Wales

A/PROF ELENA OSTROVSKAYA
**Leader, Research theme 2**
Chair, Equity & Diversity Committee
Node leader, Australian National University

PROF KRIS HELMERSON
**Leader, Research theme 3**
Monash University

PROF XIAOLIN WANG
**Leader, Enabling technology A**
Node leader, University of Wollongong

A/PROF LAN WANG
**Leader, Enabling technology B**
Node leader, RMIT University

PROF CHRIS VALE
**Chair, Outreach Committee**
Node leader, Swinburne

PROF KOUROSH KALANTAR-ZADEH
**Chair, Industry Relations Committee**
University of New South Wales / RMIT University

PROF MATTHEW DAVIS
**Chair, Education & Training Committee**
Node leader, University of Queensland

PROF NAGARAJAN 'NAGY' VALANOOR
**Chair, Communications Committee**
University of New South Wales

> FLEET is very cohesive. Even though RMIT is a smaller node, we always feel well-supported by the Operations Team, and included in Centre communications and events.
>
> **Nicci Coad**
> *Node administrator, RMIT*

## 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 p61)**.

> We have significantly expanded Committee membership this year to ensure representation from each node, and to engage more with our student and early-career researchers.
>
> **A/Prof Elena Ostrovskaya**
> Chair, Equity and Diversity Committee

## COMMITTEE MEMBERS:

A/PROF ELENA OSTROVSKAYA
**Committee Chair, ANU**

DR BABAR SHABBIR
**Research Fellow, Monash**

DR DIMI CULCER
**UNSW**

DR JEFF DAVIS
**Swinburne**

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
**Chief Operating Officer**

PROF XIAOLIN WANG
**UOW**

YONATAN ASHLEA ALAVA
**PhD student, UNSW**

## BUILDING FUTURE SCIENCE LEADERS: EDUCATION AND TRAINING COMMITTEE

FLEET is building future Australian science leaders amongst 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 p65)**.

> 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

## COMMITTEE MEMBERS:

PROF MATTHEW DAVIS
**Committee Chair, UQ**

DR DIANNE RUKA
**Education and Training Coordinator**

A/PROF ELENA OSTROVSKAYA
**ANU**

PROF JAN SEIDEL
**UNSW**

PROF JARED COLE
**RMIT**

DR JEFF DAVIS
**Swinburne**

PROF KRIS HELMERSON
**Monash**

PROF XIAOLIN WANG
**UOW**

## 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 p72).

> It's wonderful to see how eagerly FLEET members have engaged in outreach activities this year.
>
> **Prof Chris Vale**
> Chair,
> Outreach Committee

## COMMITTEE MEMBERS:

PROF CHRIS VALE
**Committee Chair, Swinburne**

DR DIANNE RUKA
**Education and Training Coordinator**

DR DIMI CULCER
**Deputy Chair, UNSW**

A/PROF ELENA OSTROVSKAYA
**ANU**

ERROL HUNT
**Communications Coordinator**

A/PROF NIKHIL MEDHEKAR
**Monash**

PROF MATTHEW DAVIS
**UQ**

> FLEET's engagement with industrial partners in 2018 is laying the groundwork for delivery of FLEET innovations into affiliated industries.
>
> **Prof Kourosh Kalantar-zadeh**
> Chair,
> Industry Relations Committee

In 2019 the Committee will be expanded to increase the involvement of Centre investigators with industry engagement, and will increase engagement with key industrial liaisons, encouraging their input into committee meetings.


*Industry panel at the FLEET Annual Workshop featured Centre Industry Liaisons and AC members.*

## RESEARCH TRANSLATION: INDUSTRY RELATIONS COMMITTEE

FLEET's Industry Relations Committee's task is 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.

## COMMITTEE MEMBERS:

PROF KOUROSH KALANTAR-ZADEH
**Committee Chair, UNSW/ RMIT**

DR JIAN-ZHEN OU
**Scientific Associate Investigator, RMIT**

A/PROF QIAOLIANG BAO
**Monash**

DR TICH-LAM NGUYEN
**Chief Operating Officer**

PROF XIAOLIN WANG
**UOW**

## 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 p80)**.

In 2018 the Communication Committee expanded its membership to include more diverse voices, including students and ECRs.

> "A highlight of FLEET communication activities in 2018 was the added dialogue between industry and academia."
>
> **Prof Nagarajan 'Nagy' Valanoor**
> Chair, Communications Committee

> "The Advisory Committee recognises and congratulates FLEET's strong, well-coordinated effort in communications, along with tangible metrics such as media mentions."
>
> **FLEET Advisory Committee**

## COMMITTEE MEMBERS:

PROF NAGARAJAN 'NAGY' VALANOOR
**Committee Chair, UNSW**

CHUTIAN WANG
**PhD student, Monash**

DR DAVID CORTIE
**Scientific Associate Investigator, UOW**

ERROL HUNT
**Communications Coordinator**

PROF JARED COLE
**RMIT**

DR JEFF DAVIS
**Swinburne**

DR DAVID COLAS
**Research Fellow, UQ**

MARYAM BOOZARJMEHR
**PhD student, ANU**

DR SAMUEL 'SAM' BLADWELL
**Research Fellow, UNSW**

DR STUART EARL
**Research Fellow, Swinburne**

# PERFORMANCE 08

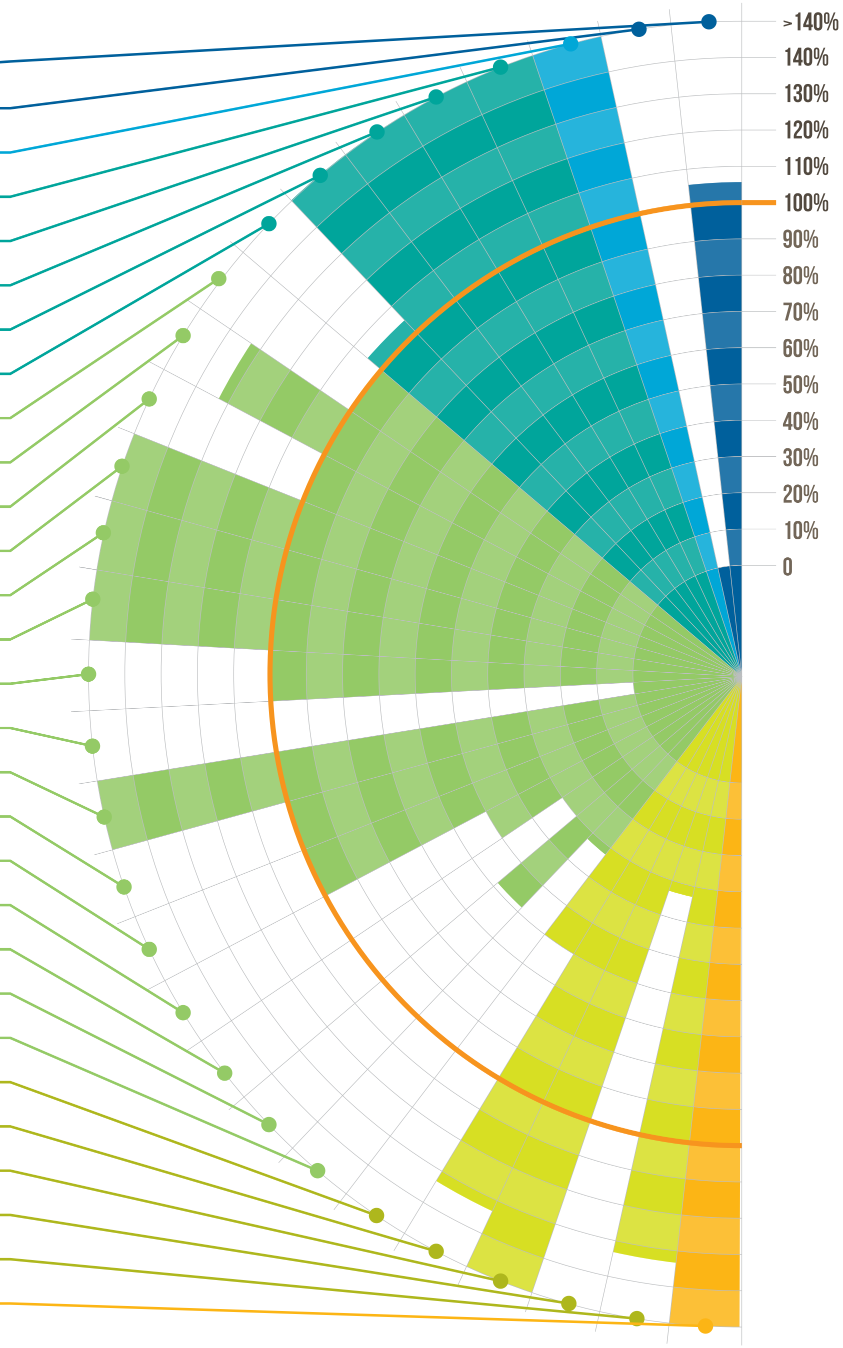
2018 marked the first full year of FLEET operations, and the Centre's scientific outputs have accelerated.

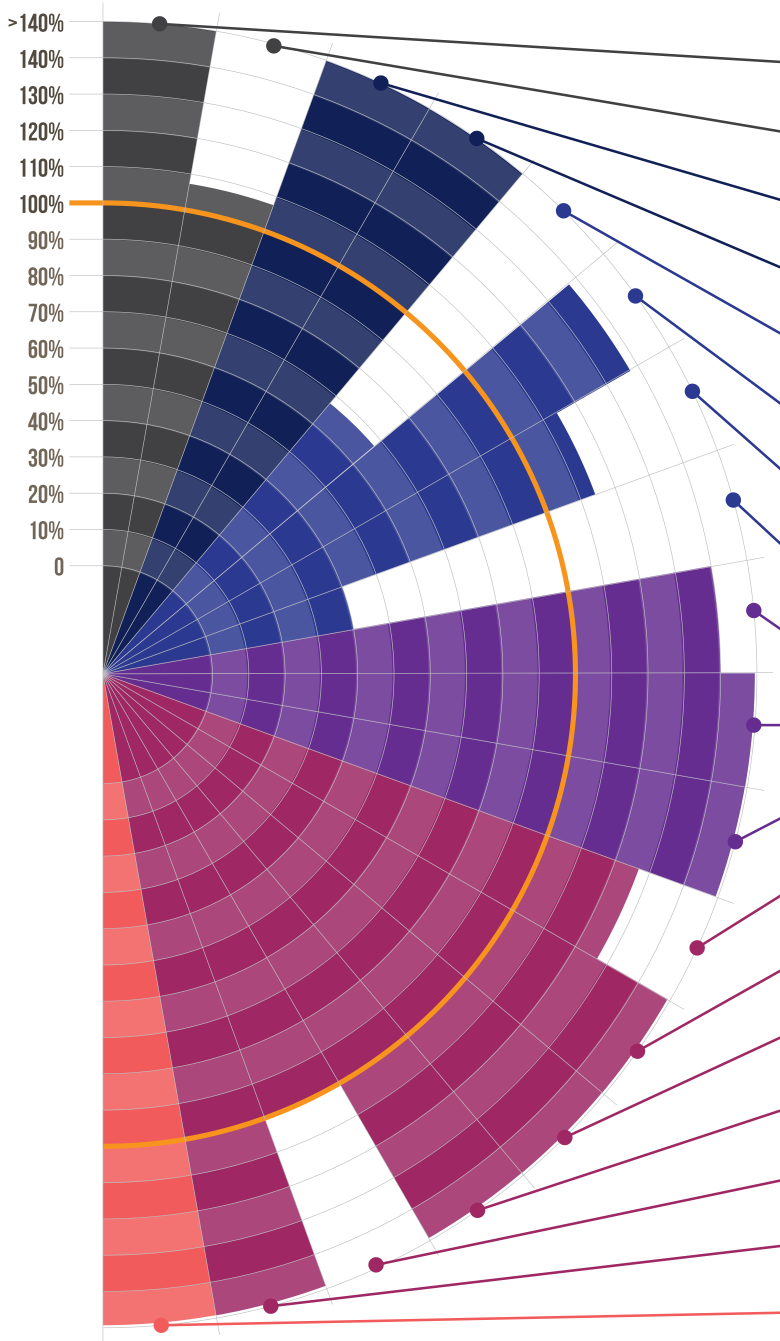
*FLEET members, 2nd Annual Workshop, Magenta NSW.*

PERFORMANCE MEASURES

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

| STANDARD KPI | Target | Actual |
|---|---|---|
| Journal articles | 60 | 64 |
| Patents applied | 1 | 0 |
| Publications in journals with IF >7 | 12 | 42 |
| Postdoctoral researchers FTE | 20 | 39 |
| Honours students | 5 | 9 |
| PhD students | 30 | 43 |
| Masters by research students | 0 | 1 |
| Associate Investigators | 24 | 25 |
| Research development courses | 3 | 3 |
| Professional development courses | 3 | 4 |
| Training workshops held on diversity and gender equity | 1 | 1 |
| Centre attendees at training workshops | 75 | 676 |
| Non-Centre attendees at training workshops | 75 | 1130 |
| Workshops held within Australia | 2 | 3 |
| Workshops held outside Australia | 2 | 2 |
| National symposium & conferences facilitated | 1 | 0 |
| International symposium & conferences facilitated | 1 | 3 |
| Number of industry engagement workshops to be held | 1 | 1 |
| Mentoring programs | 4 | 4 |
| Mentors within the Centre | 40 | 20 |
| Mentors external to the Centre | 10 | 3 |
| FLEET mentees | 50 | 29 |
| Organisational links in training and mentorship programs | 6 | 2 |
| Presentations to the public | 20 | 12 |
| Presentations to government | 3 | 4 |
| Presentations to industry/business/end-users | 3 | 12 |
| Presentations to non-government organisations | 3 | 1 |
| Presentations to professional organisations and bodies | 3 | 4 |
| New collaborating organisations | 3 | 6 |






| Actual | Target | CENTRE SPECIFIC KPI |
|---|---|---|
| 27% | 15% | **Percentage of women HDRs in FLEET** |
| 16% | 15% | **Percentage of women ECRs in FLEET** |
| 43 | 24 | **Invited talks at international conferences** |
| 3 | 2 | **New fellowships awarded to CIs, ECRs and AIs** |
| 4 | 6 | **International students and ECRs visiting FLEET** |
| 41 | 30 | **International senior investigators visiting FLEET** |
| 9 | 8 | **Chief Investigators visiting partners** |
| 4 | 10 | **ECR & HDR students visiting partners** |
| 7 | 5 | **Non-peer reviewed works by FLEET members** |
| 220 | 40 | **Mentions of FLEET research in the media** |
| 1572 | 400 | **New users to Centre website, monthly average** |
| 1551 | 1200 | **Hours spent in outreach activities** |
| 2189 | 200 | **Primary/Secondary students reached** |
| 197 | 50 | **Primary/Secondary teachers reached** |
| 11,186 | 2000 | **Public reached** |
| 6 | 6 | **Organisational links in education and outreach programs** |
| 12 | 6 | **End-user relationships established** |
| 10,429 | 1000 | **Additional research income secured by Centre staff ('000)** |

PERFORMANCE MEASURES

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

# PEER-REVIEWED PUBLICATIONS


1. J.C. Abadillo-Uriel; J. Salfi; X. Hu; S. Rogge; M.J. Calderón; D. Culcer *Entanglement control and magic angles for acceptor qubits in Si* Appl. Phys. Lett. **2018** 113 1 12102 DOI: 10.1063/1.5036521 Impact factor 4 to 7
2. N. Alaal; N. Medhekar; A. Shukla *Tunable electronic properties of partially edge-hydrogenated armchair boron-nitrogen-carbon nanoribbons* Phys. Chem. Chem. Phys. **2018** 20 15 10345 - 10358 DOI: 10.1039/C7CP08234G Impact factor 4 to 7
3. P. Atkin; D.W.M. Lau; Q. Zhang; C. Zheng; K.J. Berean; M.R. Field; J.Zhen Ou; I.S. Cole; T. Daeneke; K. Kalantar-zadeh *Laser exposure induced alteration of $WS_2$ monolayers in the presence of ambient moisture* 2D Mater. **2018** 5 1 15013 DOI: 10.1088/2053-1583/aa91b8 to Impact factor 10 *
4. P. Atkin; R. Orrell-Trigg; A. Zavabeti; N. Mahmood; M.R. Field; T. Daeneke; I.S. Cole; K. Kalantar-zadeh *Evolution of 2D tin oxides on the surface of molten tin* Chem. Commun. **2018** 54 17 2102 - 2105 DOI: 10.1039/C7CC09040D Impact factor 4 to 7 *
5. X. Bao; H. Mu; Y. Chen; P. Li; L. Li; S. Li; K. Qasim; Y. Zhang; H. Zhang; Q. Bao *Ytterbium-doped fiber laser passively mode locked by evanescent field interaction with $CH_3NH_3SnI_3$ perovskite saturable absorber* J. Phys. D: Appl. Phys. **2018** 51 37 375106 DOI: 10.1088/1361-6463/aad71d Impact factor less than 4
6. X. Bao; Q. Ou; Z.Q. Xu; Y. Zhang; Q. Bao; H. Zhang *Band Structure Engineering in 2D Materials for Optoelectronic Applications* Adv. Mater. Technol. **2018** 3 11 1800072 DOI: 10.1002/admt.201800072 Impact factor 4 to 7
7. T.D.M. Bell; G. Gauthier; T.W. Neely; H. Rubinsztein-Dunlop; M.J. Davis; M.A. Baker *Phase and micromotion of Bose-Einstein condensates in a time-averaged ring trap* Phys. Rev. A **2018** 98 1 DOI: 10.1103/PhysRevA.98.013604 Impact factor less than 4 *
8. S. Bladwell; O.P. Sushkov *Interference in spin-orbit coupled transverse magnetic focusing: Emergent phase due to in-plane magnetic fields* Phys. Rev. B **2018** 98 8 DOI: 10.1103/PhysRevB.98.085438 Impact factor 4 to 7
9. D. Colas; F.P. Laussy; M.J. Davis *Negative-Mass Effects in Spin-Orbit Coupled Bose-Einstein Condensates* Phys. Rev. Lett. **2018** 121 5 DOI: 10.1103/PhysRevLett.121.055302 Impact factor 7 to 10 *
10. J.L. Collins; A. Tadich; W. Wu; L.C. Gomes; J.N.B. Rodrigues; C. Liu; J. Hellerstedt; H. Ryu; S. Tang; S.K. Mo; S. Adam; S.A. Yang; M.S. Fuhrer; M.T. Edmonds *Electric-field-tuned topological phase transition in ultrathin $Na_3Bi$* Nature **2018** 564 7736 390 - 394 DOI: 10.1038/s41586-018-0788-5 Impact factor >10 *#
11. R.S. Datta; J.Zhen Ou; M. Mohiuddin; B.J. Carey; B.Yue Zhang; H. Khan; N. Syed; A. Zavabeti; F. Haque; T. Daeneke; K. Kalantar-zadeh *Two dimensional $PbMoO_4$: A photocatalytic material derived from a naturally non-layered crystal* Nano Energy **2018** 49 237 - 246 DOI: 10.1016/j.nanoen.2018.04.041 Impact factor >10 *
12. N. Dhar; N. Syed; M. Mohiuddin; A. Jannat; A. Zavabeti; B.Yue Zhang; R.S. Datta; P. Atkin; N. Mahmood; D. Esrafilzadeh; T. Daeneke; K. Kalantar-zadeh *Exfoliation Behavior of van der Waals Strings: Case Study of $Bi_2S_3$* ACS Appl. Mater. Interfaces **2018** 10 49 42603 - 42611 DOI: 10.1021/acsami.8b14702 Impact factor 7 to 10 *
13. E. Estrecho; T. Gao; N. Bobrovska; M.D. Fraser; M. Steger; L. Pfeiffer; K. West; T.C.H. Liew; M. Matuszewski; D.W. Snoke; A.G. Truscott; E.A. Ostrovskaya *Single-shot condensation of exciton polaritons and the hole burning effect* Nat. Commun. **2018** 9 1 DOI: 10.1038/s41467-018-05349-4 Impact factor >10
14. M.A. Fogarty; K.W. Chan; B. Hensen; W. Huang; T. Tanttu; C.H. Yang; A. Laucht; M. Veldhorst; F.E. Hudson; K.M. Itoh; D. Culcer; T.D. Ladd; A. Morello; A.S. Dzurak *Integrated silicon qubit platform with single-spin addressability, exchange control and single-shot singlet-triplet readout* Nat. Commun. **2018** 9 1 DOI: 10.1038/s41467-018-06039-x Impact factor >10
15. T. Gao; O.A. Egorov; E. Estrecho; K. Winkler; M. Kamp; C. Schneider; S. Höfling; A.G. Truscott; E.A. Ostrovskaya *Controlled Ordering of Topological Charges in an Exciton-Polariton Chain* Phys. Rev. Lett. **2018** 121 22 DOI: 10.1103/PhysRevLett.121.225302 Impact factor 7 to 10 #
16. T. Gao; G. Li; E. Estrecho; T.C.H. Liew; D. Comber-Todd; A. Nalitov; M. Steger; K. West; L. Pfeiffer; D.W. Snoke; A.V. Kavokin; A.G. Truscott; E.A. Ostrovskaya *Chiral Modes at Exceptional Points in Exciton-Polariton Quantum Fluids* Phys. Rev. Lett. **2018** 120 6 DOI: 10.1103/PhysRevLett.120.065301 Impact factor 7 to 10
17. H. Hapuarachchi; S.D. Gunapala; Q. Bao; M.I. Stockman; M. Premaratne *Exciton behavior under the influence of metal nanoparticle near fields: Significance of nonlocal effects* Phys. Rev. B **2018** 98 11 DOI: 10.1103/PhysRevB.98.115430 Impact factor less than 4
18. A. Hsain; P. Sharma; H. Yu; J.L. Jones; F. So; J. Seidel *Enhanced piezoelectricity of thin film hafnia-zirconia (HZO) by inorganic flexible substrates* Appl. Phys. Lett. **2018** 113 2 22905 DOI: 10.1063/1.5031134 Impact factor 4 to 7
19. S. Hu; C. Cazorla; F. Xiang; H. Ma; J. Wang; J. Wang; X.L. Wang; C. Ulrich; L. Chen; J. Seidel *Strain Control of Giant Magnetic Anisotropy in Metallic Perovskite $SrCoO_{3-\delta}$ Thin Films* ACS Appl. Mater. Interfaces **2018** 10 26 22348 - 22355 DOI: 10.1021/acsami.8b03553 Impact factor 7 to 10
20. X. Jiang; S. Liu; W. Liang; S. Luo; Z. He; Y. Ge; H. Wang; R. Cao; F. Zhang; Q. Wen; J. Li; Q. Bao; D. Fan; H. Zhang *Broadband Nonlinear Photonics in Few-Layer MXene $Ti_3C_2T_x$ (T = F, O, or OH)* Laser & Photonics Reviews **2018** 12 2 1700229 DOI: 10.1002/lpor.201700229 Impact factor 7 to 10
21. C. Krull; M. Castelli; P. Hapala; D. Kumar; A. Tadich; M. Capsoni; M.T. Edmonds; J. Hellerstedt; S.A. Burke; P. Jelinek; A. Schiffrin *Iron-based trinuclear metal-organic nanostructures on a surface with local charge accumulation* Nat. Commun. **2018** 9 1 DOI: 10.1038/s41467-018-05543-4 Impact factor >10 *#
22. T.P. Le; J. Levinsen; K. Modi; M.M. Parish; F.A. Pollock *Spin-chain model of a many-body quantum battery* Phys. Rev. A **2018** 97 2 DOI: 10.1103/PhysRevA.97.022106 Impact factor less than 4
23. H. Liu; E. Marcellina; A.R. Hamilton; D. Culcer *Strong Spin-Orbit Contribution to the Hall Coefficient of Two-Dimensional Hole Systems* Phys. Rev. Lett. **2018** 121 8 DOI: 10.1103/PhysRevLett.121.087701 Impact factor 7 to 10
24. Y. Liu; J. Besbas; Y. Wang; P. He; M. Chen; D. Zhu; Y. Wu; J.Min Lee; L. Wang; J. Moon; N. Koirala; S. Oh; H. Yang *Direct visualization of current-induced spin accumulation in topological insulators* Nat.

Commun. **2018** 9 1 DOI: 10.1038/s41467-018-04939-6 Impact factor >10

25. Z. Liu; X. Zhang; B. Wang; M. Xia; S. Gao; X. Liu; A. Zavabeti; J.Zhen Ou; K. Kalantar-zadeh; Y. Wang *Amorphous $MoS_x$ -Coated $TiO_2$ Nanotube Arrays for Enhanced Electrocatalytic Hydrogen Evolution Reaction* J. Phys. Chem. C **2018** 122 24 12589 - 12597 DOI: 10.1021/acs.jpcc.8b01678 Impact factor 4 to 7 *

26. W. Ma; P. Alonso-González; S. Li; A.Y. Nikitin; J. Yuan; J. Martín-Sánchez; J. Taboada-Gutiérrez; I. Amenabar; P. Li; S. Vélez; C. Tollan; Z. Dai; Y. Zhang; S. Sriram; K. Kalantar-zadeh; S.T. Lee; R. Hillenbrand; Q. Bao *In-plane anisotropic and ultra-low-loss polaritons in a natural van der Waals crystal* Nature **2018** 562 7728 557 - 562 DOI: 10.1038/s41586-018-0618-9 Impact factor >10

27. K.A. Messalea; B.J. Carey; A. Jannat; N. Syed; M. Mohiuddin; B.Yue Zhang; A. Zavabeti; T. Ahmed; N. Mahmood; E.Della Gaspera; K. Khoshmanesh; K. Kalantar-zadeh; T. Daeneke *$Bi_2O_3$ monolayers from elemental liquid bismuth* Nanoscale **2018** 10 33 15615 - 15623 DOI: 10.1039/C8NR03788D Impact factor 7 to 10 *

28. C. Mller; S. Guan; N. Vogt; J.H. Cole; T.M. Stace *Passive On-Chip Superconducting Circulator Using a Ring of Tunnel Junctions* Phys. Rev. Lett. **2018** 120 21 DOI: 10.1103/PhysRevLett.120.213602 Impact factor 7 to 10

29. M. Mohiuddin; N. Pillai; A. Zavabeti; N. Mahmood; N. Syed; R.S. Datta; D. Jampaiah; T. Daeneke; J.Zhen Ou; K. Kalantar-zadeh *Exploring electric field assisted van der Waals weakening of stratified crystals* Applied Materials Today **2018** 12 359 - 365 DOI: 10.1016/j.apmt.2018.05.005 Impact factor less than 4 *

30. M. Mohiuddin; Y. Wang; A. Zavabeti; N. Syed; R.S. Datta; H. Ahmed; T. Daeneke; S.P. Russo; A.R. Rezk; L.Y. Yeo; K. Kalantar-zadeh *Liquid Phase Acoustic Wave Exfoliation of Layered $MoS_2$ : Critical Impact of Electric Field in Efficiency* Chem. Mater. **2018** 30 16 5593 - 5601 DOI: 10.1021/acs.chemmater.8b01506 Impact factor 7 to 10

31. Q. Ou; Y. Zhang; Z. Wang; J.A. Yuwono; R. Wang; Z. Dai; W. Li; C. Zheng; Z.Q. Xu; X. Qi; S. Duhm; N. Medhekar; H. Zhang; Q. Bao *Strong Depletion in Hybrid Perovskite p-n Junctions Induced by Local Electronic Doping* Adv. Mater. **2018** 30 15 1705792 DOI: 10.1002/adma.v30.15,10.1002/adma.201705792 Impact factor >10

32. T. Peppler; P. Dyke; M. Zamorano; I. Herrera; S. Hoinka; C.J. Vale *Quantum Anomaly and 2D-3D Crossover in Strongly Interacting Fermi Gases* Phys. Rev. Lett. **2018** 121 12 DOI: 10.1103/PhysRevLett.121.120402 Impact factor less than 4 *

33. X. Qi; Y. Zhang; Q. Ou; S.Tung Ha; C.W. Qiu; H. Zhang; Y.B. Cheng; Q. Xiong; Q. Bao *Photonics and Optoelectronics of 2D Metal-Halide Perovskites* Small **2018** 14 31 1800682 DOI: 10.1002/smll.v14.31,10.1002/smll.201800682 Impact factor 7 to 10

34. D. Sando; C. Carrétéro; M.N. Grisolia; A. Barthélémy; V. Nagarajan; M. Bibes *Revisiting the Optical Band Gap in Epitaxial $BiFeO_3$ Thin Films* Advanced Optical Materials **2018** 6 2 1700836 DOI: 10.1002/adom.v6.2,10.1002/adom.201700836 Impact factor 7 to 10

35. D. Sando; T. Young; R. Bulanadi; X. Cheng; Y. Zhou; M. Weyland; P. Munroe; V. Nagarajan *Designer defect stabilization of the super tetragonal phase in >70-nm-thick $BiFeO_3$ films on $LaAlO_3$ substrates* Jpn. J. Appl. Phys. **2018** 57 9 0902B2 DOI: 10.7567/JJAP.57.0902B2 Impact factor less than 4

36. D. Sando; Y. Yang; C. Paillard; B. Dkhil; L. Bellaiche; V. Nagarajan *Epitaxial ferroelectric oxide thin films for optical applications* Applied Physics Reviews **2018** 5 4 41108 DOI: 10.1063/1.5046559 Impact factor >10

37. A. Schiffrin; M. Capsoni; G. Farahi; C.G. Wang; C. Krull; M. Castelli; T. Roussy; K.A. Cochrane; Y. Yin; N. Medhekar; M.S. Fuhrer; A.Q. Shaw; W. Ji; S.A. Burke *Designing Optoelectronic Properties by On-Surface Synthesis: Formation and Electronic Structure of an Iron-Terpyridine Macromolecular Complex* ACS Nano **2018** DOI: 10.1021/acsnano.8b01026 IImpact factor >10

38. B. Shabbir; M. Nadeem; Z. Dai; M.S. Fuhrer; Q.K. Xue; X.L. Wang; Q. Bao *Long range intrinsic ferromagnetism in two dimensional materials and dissipationless future technologies* Applied Physics Reviews **2018** 5 4 41105 DOI: 10.1063/1.5040694 Impact factor >10 #

39. P. Sharma; Z. Huang; M. Li; C. Li; S. Hu; H. Lee; J.W. Lee; C.B. Eom; S.J. Pennycook; J. Seidel; Ariando; A. Gruverman *Oxygen Stoichiometry Effect on Polar Properties of $LaAlO_3/SrTiO_3$* Adv. Funct. Mater. **2018** 28 23 1707159 DOI: 10.1002/adfm.v28.23,10.1002/adfm.201707159 Impact factor >10

40. N. Syed; A. Zavabeti; J.Zhen Ou; M. Mohiuddin; N. Pillai; B.J. Carey; B.Yue Zhang; R.S. Datta; A. Jannat; F. Haque; K.A. Messalea; C. Xu; S.P. Russo; C.F. McConville; T. Daeneke; K. Kalantar-zadeh *Printing two-dimensional gallium phosphate out of liquid metal* Nat. Commun. **2018** 9 1 DOI: 10.1038/s41467-018-06124-1 Impact factor >10 *

41. M.L.V. Tagliaferri; P.L. Bavdaz; W. Huang; A.S. Dzurak; D. Culcer; M. Veldhorstm*Impact of valley phase and splitting on readout of silicon spin qubits* Phys. Rev. B **2018** 97 24 DOI: 10.1103/PhysRevB.97.245412 Impact factor 4 to 7

42. C. Tan; J. Lee; S.G. Jung; T. Park; S. Albarakati; J. Partridge; M.R. Field; D.G. McCulloch; L. Wang; C. Lee *Hard magnetic properties in nanoflake van der Waals $Fe_3GeTe_2$* Nat. Commun. **2018** 9 1 DOI: 10.1038/s41467-018-04018-w Impact factor >10

43. C. Tan; Z. Yue; Z. Dai; Q. Bao; X.L. Wang; H. Lu; L. Wang *Nanograting-assisted generation of surface plasmon polaritons in Weyl semimetal $WTe_2$* Optical Materials **2018** 86 421 - 423 DOI: 10.1016/j.optmat.2018.10.042 Impact factor less than 4

44. M. Tuo; C. Xu; H. Mu; X. Bao; Y. Wang; S. Xiao; W. Ma; L. Li; D. Tang; H. Zhang; M. Premaratne; B. Sun; H.M. Cheng; S. Li; W. Ren; Q. Bao *Ultrathin 2D Transition Metal Carbides for Ultrafast Pulsed Fiber Lasers* ACS Photonics **2018** 5 5 1808 - 1816 DOI: 10.1021/acsphotonics.7b01428 Impact factor 7 to 10

45. J.A. Vaitkus; J.H. Cole *Bttiker probes and the recursive Green's function: An efficient approach to include dissipation in general configurations* Phys. Rev. B **2018** 97 8 DOI: 10.1103/PhysRevB.97.085149 Impact factor less than 4

46. M. Waldherr; N. Lundt; M. Klaas; S. Betzold; M. Wurdack; V. Baumann; E. Estrecho; A. Nalitov; E. Cherotchenko; H. Cai; E.A. Ostrovskaya; A.V. Kavokin; S. Tongay; S. Klembt; S. Höfling; C. Schneider *Observation of bosonic condensation in a hybrid monolayer $MoSe_2$-GaAs microcavity* Nat. Commun. **2018** 9 1 DOI: 10.1038/

s41467-018-05532-7 Impact factor >10 #

47. X. Wang; T. Li; Z. Cheng; X.L. Wang; H. Chen *Recent advances in Dirac spin-gapless semiconductors* Applied Physics Reviews **2018** 5 4 41103 DOI: 10.1063/1.5042604 Impact factor >10

48. Z. Wang; Q. Ou; Y. Zhang; Q. Zhang; H. Hoh; Q. Bao *Degradation of two-dimensional $CH_3NH_3PbI_3$ perovskite and $CH_3NH_3PbI_3$/graphene heterostructure* ACS Appl. Mater. Interfaces **2018** DOI: 10.1021/acsami.8b04310 Impact factor 7 to 10

49. X. Wen; W. Chen; J. Yang; Q. Ou; T. Yang; C. Zhou; H. Lin; Z. Wang; Y. Zhang; G. Conibeer; Q. Bao; B. Jia; D.J. Moss *Role of Surface Recombination in Halide Perovskite Nanoplatelets* ACS Appl. Mater. Interfaces **2018** 10 37 31586 - 31593 DOI: 10.1021/acsami.8b06931 Impact factor 7 to 10

50. S.A. Wilkinson; N. Vogt; D.S. Golubev; J.H. Cole *Approximate solutions to Mathieu's equation* Physica E: Low-dimensional Systems and Nanostructures **2018** 100 24 - 30 DOI: 10.1016/j.physe.2018.02.019 Impact factor less than 4

51. F.X. Xiang; A. Srinivasan; Z.Z. Du; O. Klochan; S.X. Dou; A.R. Hamilton; X.L. Wang *Thickness-dependent electronic structure in $WTe_2$ thin films* Phys. Rev. B **2018** 98 3 DOI: 10.1103/PhysRevB.98.035115 Impact factor less than 4

52. J. Yang; W. Yu; Z. Pan; Q. Yu; Q. Yin; L. Guo; Y. Zhao; T. Sun; Q. Bao; K. Zhang *Ultra-Broadband Flexible Photodetector Based on Topological Crystalline Insulator SnTe with High Responsivity* Small **2018** 14 37 1802598 DOI: 10.1002/smll.v14.37,10.1002/smll.201802598 Impact factor 7 to 10

53. Q. Yang; C. Zhang; S. Wu; S. Li; Q. Bao; V. Giannini; S.A. Maier; X. Li *Photonic surface waves enabled perfect infrared absorption by monolayer graphene* Nano Energy **2018** 48 161 - 169 DOI: 10.1016/j.nanoen.2018.03.048 Impact factor >10

54. J. Yuan; H. Mu; L. Li; Y. Chen; W. Yu; K. Zhang; B. Sun; S. Lin; S. Li; Q. Bao *Few-Layer Platinum Diselenide as a New Saturable Absorber for Ultrafast Fiber Lasers* ACS Appl. Mater. Interfaces **2018** 10 25 21534 - 21540 DOI: 10.1021/acsami.8b03045 Impact factor 7 to 10

55. J. Yuan; T. Sun; Z. Hu; W. Yu; W. Ma; K. Zhang; B. Sun; S.Ping Lau; Q. Bao; S. Lin; S. Li *Wafer-Scale Fabrication of Two-Dimensional $PtS_2$/$PtSe_2$ Heterojunctions for Efficient and Broad band Photodetection* ACS Appl. Mater. Interfaces **2018** 10 47 40614 - 40622 DOI: 10.1021/acsami.8b13620 Impact factor 7 to 10

56. T. Young; P. Sharma; D.H. Kim; T.Duy Ha; J.Y. Juang; Y.H. Chu; J. Seidel; V. Nagarajan; S. Yasui; M. Itoh; D. Sando *Structural, magnetic, and ferroelectric properties of T-like cobalt-doped $BiFeO_3$ thin films* APL Materials **2018** 6 2 26102 DOI: 10.1063/1.5011783 Impact factor 4 to 7

57. M. Zarenia, A.R. Hamilton, F.M. Peeters and D. Neilson *Multiband Mechanism for the Sign Reversal of Coulomb Drag Observed in Double Bilayer Graphene Heterostructures* Phys. Rev. Lett. **2018** 121 036601 DOI: 10.1103/PhysRevLett.121.036601 Impact factor 7 to 10*

58. A. Zavabeti; B.Yue Zhang; I.Alves de Castro; J.Zhen Ou; B.J. Carey; M. Mohiuddin; R.S. Datta; C. Xu; A.P. Mouritz; C.F. McConville; A.P. O'Mullane; T. Daeneke; K. Kalantar-zadeh *Green Synthesis of Low-Dimensional Aluminum Oxide Hydroxide and Oxide Using Liquid Metal Reaction Media: Ultrahigh Flux Membranes* Adv. Funct. Mater. **2018** 28 44 1804057 DOI: 10.1002/adfm.v28.44,10.1002/adfm.201804057 Impact factor >10 *

59. H. Zhang; Q. Bao; Z. Sun *Introduction to two-dimensional layered materials for ultrafast lasers* Photon. Res. **2018** 6 10 TDL1 DOI: 10.1364/PRJ.6.00TDL1 Impact factor 4 to 7

60. F. Zhang; K. Chen; X. Jiang; Y. Wang; Y. Ge; L. Wu; S. Xu; Q. Bao; H. Zhang *Nonlinear optical absorption and ultrafast carrier dynamics of copper antimony sulfide semiconductor nanocrystals* J. Mater. Chem. C **2018** 6 33 8977 - 8983 DOI: 10.1039/C8TC01606B Impact factor 4 to 7

61. Q. Zhang; J. Lu; Z. Wang; Z. Dai; Y. Zhang; F. Huang; Q. Bao; W. Duan; M.S. Fuhrer; C. Zheng *Reliable Synthesis of Large-Area Monolayer $WS_2$ Single Crystals, Films, and Heterostructures with Extraordinary Photoluminescence Induced by Water Intercalation* Advanced Optical Materials **2018** 6 12 1701347 DOI: 10.1002/adom.v6.12,10.1002/adom.201701347 Impact factor 7 to 10

62. L. Zhang; A. Sharma; Y. Zhu; Y. Zhang; B. Wang; T. Daeneke; H.T. Nguyen; Z. Wang; B. Wen; Y. Cao; B. Liu; X. Sun; J. Yang; Z. Li; A. Kar; Y. Shi; D. Macdonald; Z. Yu; X. Wang; Y. Lu *Efficient and Layer-Dependent Exciton Pumping across Atomically Thin Organic-Inorganic Type-I Heterostructures* Adv. Mater. **2018** 30 40 1803986 DOI: 10.1002/adma.v30.40,10.1002/adma.201803986 Impact factor >10 *

63. C. Zheng; L. Yu; L. Zhu; J.L. Collins; D. Kim; Y. Lou; C. Xu; M. Li; Z. Wei; Y. Zhang; M.T. Edmonds; S. Li; J. Seidel; Y. Zhu; J.Zhe Liu; W.X. Tang; M.S. Fuhrer *Room temperature in-plane ferroelectricity in van der Waals $In_2Se_3$* Science Advances **2018** 4 7 eaar7720 DOI: 10.1126/sciadv.aar7720 Impact factor >10 *

64. C. Zhou; Q. Ou; W. Chen; Z. Gan; J. Wang; Q. Bao; X. Wen; B. Jia *Illumination-Induced Halide Segregation in Gradient Bandgap Mixed-Halide Perovskite Nanoplatelets* Advanced Optical Materials **2018** 6 24 1801107 DOI: 10.1002/adom.v6.24,10.1002/adom.201801107 Impact factor 7 to 10


## CONFERENCE PROCEEDINGS


1. D. Culcer; H. Liu; A. Sekine; A.H. MacDonald; E. Marcellina; A.R. Hamilton *Anomalies in magneto-transport in spin-orbit coupled systems* Spintronics XI **2018** SPIE United States DOI: 10.1117/12.2323582 #

2. M.Ranjan Panda; A.Raj K.; Q. Bao; S. Mitra *$MoTe_2$ A novel anode material for sodium ion battery* 62nd DAE Solid State Physics Symposium **2018** AIP United States DOI: 10.1063/1.5029209


*DOI Article Digital object identifier*

** publications involving associate investigators*

*# publications involving partner investigators*

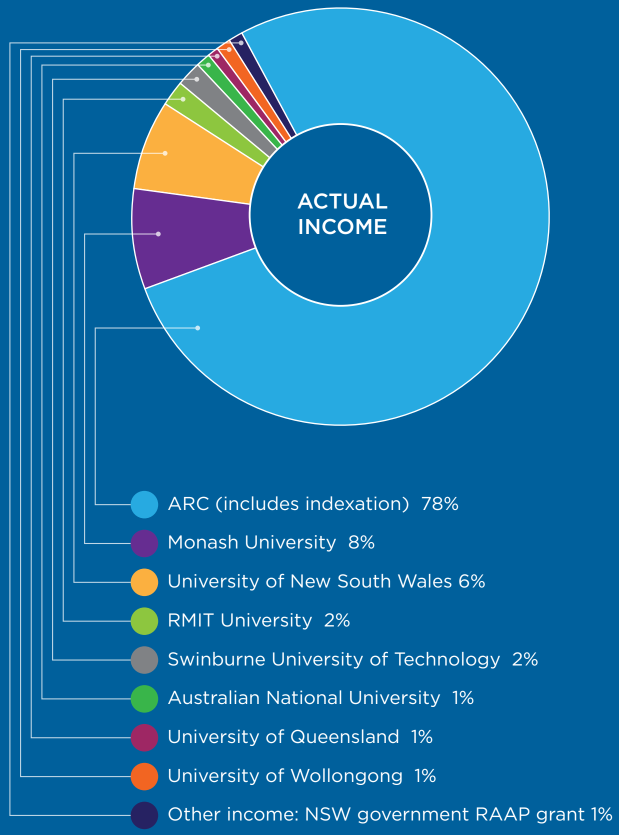
*Impact factor at time of publication*

# AWARDS, HONOURS AND GRANTS

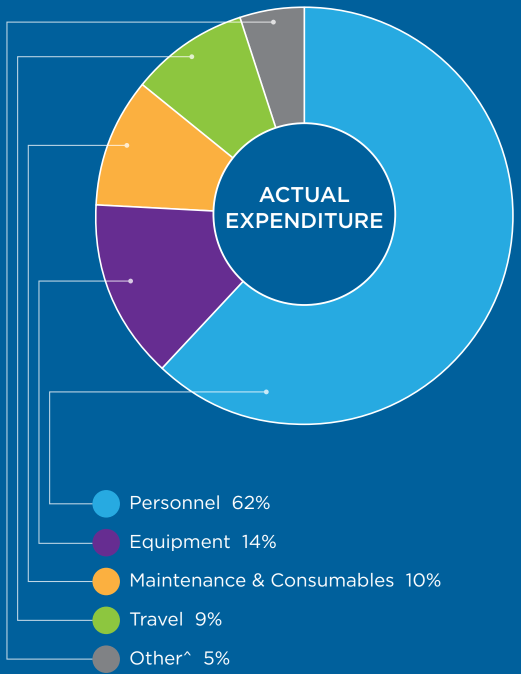
| FLEET MEMBER INVOLVED | TITLE OF FUNDING SCHEME OR AWARD | PROJECT ID | TOTAL AMOUNT OF FUNDING (AUD) | FUNDING SOURCE / AWARDEE |
|---|---|---|---|---|
| Chris Vale, Matthew Davis, Kristian Helmerson, Meera Parish | Linkage Infrastructure, Equipment and Facilities | LE180100142 | $727,900 | Australian Research Council |
| David Cortie | Discovery Early Career Researcher Award (DECRA) | DE180100314 | $353,773 | Australian Research Council |
| Jan Seidel | Linkage Infrastructure, Equipment and Facilities | LE180100109 | $832,648 | Australian Research Council |
| Jan Seidel | Linkage Infrastructure, Equipment and Facilities | LE180100054 | $832,648 | Australian Research Council |
| Jan Seidel, Nagarajan Valanoor, Oleg Sushkov | Linkage Infrastructure, Equipment and Facilities | LE180100109 | $832,648 | Australian Research Council |
| Jared Cole | Linkage Infrastructure, Equipment and Facilities | LE180100037 | $223,039 | Australian Research Council |
| Jian-zhen Ou | Discovery Projects | DP180102752 | $307,239 | Australian Research Council |
| Jian-zhen Ou, Qiaoliang Bao | Linkage Infrastructure, Equipment and Facilities | LE180100030 | $541,705 | Australian Research Council |
| Kourosh Kalantar-zadeh | ARC Laureate Fellowship | FL180100053 | $3,162,000 | Australian Research Council |
| Kristian Helmerson | Discovery Projects | DP180100872 | $402,993 | Australian Research Council |
| Lan Wang | Linkage Infrastructure, Equipment and Facilities | LE180100150 | $595,280 | Australian Research Council |
| Michael Fuhrer, Mark Edmonds, Kourosh Kalantar-zadeh, Lan Wang, Jian-zhen Ou, Jan Seidel, Yuerui (Larry) Lu | Linkage Infrastructure, Equipment and Facilities | LE180100054 | $824,080 | Australian Research Council |
| Yuerui (Larry) Lu | Discovery Projects | DP180103238 | $402,934 | Australian Research Council |
| Xiaolin Wang | Lee Hsun Research Award on Materials Science | | | Chinese Academy of Sciences |
| Lan Wang, Jared Cole | Lockheed Martin collaborative grant | | Confidential | Lockheed Martin Pty Ltd |
| Harley Scammell | Fulbright Postdoctoral Scholarship, Sponsored by Monash University | | | Monash University |
| Mark Edmonds | Monash Centre for Atomically Thin Materials Grants | | $35,000 | Monash University |
| Mark Edmonds, Michael Fuhrer, Agustin Schiffrin | Monash Centre for Atomically Thin Materials Grants | | $20,050 | Monash University |
| Ziyu Wang | Outstanding Poster Prizes | | | Nanyang Technological University Singapore |
| Ali Zavabeti | Ford publication prize | | $1,000 | RMIT University |
| Kourosh Kalantar-zadeh | 2018 American Chemical Society (ACS) Advances in Measurement Science Lectureship Award (Asia-Pacific region) | | $3,500 | RMIT University |
| Torben Daeneke | RMIT Award for Research Excellence - ECR Technology | | $3,000 | RMIT University |
| Carlos Claiton Noschang Kuhn | Faculty of Science Engineering and Technology Travel Grant | | $1,200 | Swinburne University |
| Oleh Klochan | UNSW Research Infrastructure Scheme | | $100,000 | University of New South Wales |
| Tich-Lam Nguyen | VESKI Leading the Way - Women in STEM Side-by-Side | | | Victorian State Government |

# 2018 INCOME AND EXPENDITURE

| REPORTING PERIOD | 2018 | 2019 |
|---|---|---|
| | | |
| CARRY FORWARD FROM 2017 | 3,866,251 | |
| **INCOME** | **Actual ($)** | **Forecast ($)** |
| ARC (includes indexation) 78% | 4,842,058 | 4,750,000 |
| Monash University 8% | 496,000 | 496,000 |
| University of New South Wales 6% | 349,531 | 404,667 |
| RMIT University 2% | 154,572 | 154,667 |
| Swinburne University of Technology 2% | 116,000 | 116,000 |
| Australian National University 1% | 58,000 | 58,000 |
| University of Queensland 1% | 58,000 | 57,999 |
| University of Wollongong 1% | 58,000 | 58,000 |
| Other income: NSW government RAAP grant 1% | 70,000 | - |
| **TOTAL INCOME** | **6,202,161** | **6,095,333** |
| **EXPENDITURE** | **Actual ($)** | **Commitment ($)** |
| Personnel | 3,307,075 | 4,154,284 |
| Equipment | 752,942 | 257,855 |
| Maintenance & Consumables | 565,116 | 440,840 |
| Travel | 464,178 | 602,188 |
| Centre Strategic Fund | - | 122,293 |
| Other | 280,166 | 459,433 |
| **TOTAL EXPENDITURE** | **5,369,477** | **6,036,893** |
| **CARRY FORWARD TO 2019** | **4,698,933** | |



# COLLABORATING ORGANISATION IN-KIND CONTRIBUTIONS




**^OTHER INCLUDES:**
Equity & diversity initiatives
Centre workshops
Annual report
Branding, marketing and PR
Education, training and outreach programs
Hosting visitors
Administrative support

| CONTRIBUTING ORGANISATION | 2018 ACTUAL ($) | 2019 COMMITMENT ($) |
|---|---|---|
| Monash University | 1,013,376 | 689,857 |
| University of New South Wales | 455,750 | 759,041 |
| RMIT University | 351,509 | 345,301 |
| Swinburne University of Technology | 362,089 | 318,195 |
| Australian National University | 216,223 | 67,380 |
| University of Queensland | 95,768 | 159,529 |
| University of Wollongong | 110,987 | 126,921 |
| Australian Nuclear Science and Technology Organisation | 308,480 | 436,000 |
| Australian Synchrotron | 363,418 | 240,465 |
| Beijing Computational Science and Research Center | N/A | 63,000 |
| California Institute of Technology, USA | 26,900 | 26,800 |
| Columbia University, USA | 16,200 | 36,200 |
| Johannes Gutenberg-Universitat Mainz, Germany | 10,200 | 30,200 |
| Joint Quantum Insitute, USA | 102,816 | 30,000 |
| Max Planck Institute of Quantum Optics, Germany | 17,925 | 34,425 |
| National University of Singapore, Singapore | 52,812 | 99,000 |
| Tsinghua University, China | 67,908 | 118,500 |
| Universitat Wurzburg, Germany | 27,512 | 19,512 |
| University of Camerino | 18,870 | 14,129 |
| University of Colorado Boulder, USA | 21,000 | 17,000 |
| University of Maryland, USA | 176,875 | 62,700 |
| University of Texas, USA | 18,000 | 31,000 |
| Wroclaw University of Science and Technology | N/A | 26,800 |
| **TOTAL IN-KIND CONTRIBUTIONS** | **3,834,618** | **3,751,955** |

# VISITORS TO FLEET NODES

| NAME OF VISITOR | INSTITUTION | COUNTRY | POSITION | VISIT DATES | NODES VISITED |
|---|---|---|---|---|---|
| Prof. Amadeo Vázquez de Parga | Universidad Autónoma de Madrid | Spain | Collaborator | 22 January 2018 -21 December 2018 | Monash |
| Prof. Pu Yu | Tsinghua University | China | Partner Investigator | 30 January 2018 - 11 February 2018 | Monash, UNSW, UOW |
| Prof. Shuyun Zhou | Tsinghua University | China | Partner Investigator | 30 January 2018 - 11 February 2018 | Monash, UNSW, UOW |
| Prof. Laurent Bellaiche | University of Arkansas | United States | Collaborator | 4 February 2018 - 11 February 2018 | Monash, UNSW |
| Prof. David Snoke | University of Pittsburgh | United States | Collaborator | 15 February 2018 - 17 August 2018 | ANU |
| Prof. Vladislav Kataev | Leibniz Institute for Solid State and Materials Research | Germany | Collaborator | 10 March 2018 | UNSW |
| Dr. Blanca Biel | University of Granada | Spain | Visiting Research Fellow | 14 March 2018 | Monash |
| Prof Bala Kavaipatti | Indian Institute of Technology, Bombay | India | Collaborator | 5 April 2018 | UNSW |
| Prof. Wen-Xin Tang | Chongqing University | China | Collaborator | 10 May 2018 | Monash |
| A/Prof. Timothy Liew | Nanyang Technological University | Singapore | Collaborator | 6 June 2018 - 19 June 2018 | ANU |
| Prof. Jianjung Zhang | Chinese Academy of Sciences | China | Collaborator | 15 June 2018 | UNSW |
| A/Prof. Shaffique Adam | National University of Singapore | Singapore | Partner Investigator | 4 July 2018 - 10 August 2018 | Monash, UNSW, Swinburne |
| Prof. Victor Gurarie | University of Colorado Boulder | United States | Partner Investigator | 12 July 2018 -13 August 2018 | Monash, Swinburne |
| A/Prof. Michael Fraser | RIKEN | Japan | Collaborator | 22 July 2018 - 1 August 2018 | ANU |
| Dr. Clemens Müller | ETH Zurich | Switzerland | Visiting Research Fellow | 30 July 2018 - 2 August 2018 | RMIT, UQ |
| Prof. Atsushi Fujimori | University of Tokyo | Japan | Collaborator | 8 August 2018 - 8 September 2018 | Monash |
| A/Prof. Dario Poletti | Singapore University of Technology and Design | Singapore | Collaborator | 13 August 2018 - 17 August 2018 | ANU |
| Dr Yimei Zhu | Department of Energy Brookhaven National Laboratory | United States | Collaborator | 14 September 2018 | UNSW |
| Yannick Schön | Karlsruhe Institute of Technology | Germany | Visiting PhD Student | 3 October 2018 - 23 January 2019 | RMIT |
| Prof. David Nielson | University of Camerino / University of Antwerp | Italy/Belgium | Partner Investigator | 3 October 2018 - 18 December 2018 | UNSW |
| Prof. Yijin Zhang | Max Planck Institute for Quantum Optics | Germany | Collaborator | 31 October 2018 - 2 November 2018 | UNSW |
| Prof. Ding Zhang | Tsinghua University | China | Collaborator | 1 November 2018 - 2 November 2018 | UNSW |
| Prof. Garnett Bryant | University of Maryland | United States | Collaborator | 16 November 2018 | UNSW |
| Prof. Gotz Uhrig | Technical University of Dortmund | Germany | Collaborator | 22 November 2018 | UNSW |

| NAME OF VISITOR | INSTITUTION | COUNTRY | POSITION | VISIT DATES | NODES VISITED |
|---|---|---|---|---|---|
| Prof. Simon Brown | University of Canterbury | New Zealand | Collaborator | 1 December 2018 - 14 December 2018 | Monash |
| Prof. Laurent Bellaiche | University of Arkansas | United States | Collaborator | 1 December 2018 - 15 December 2018 | UNSW |
| Prof. Michele Governale | Victoria University of Wellington | New Zealand | Collaborator | 1 December 2018 - 15 December 2018 | UNSW |
| Prof. Simon Granville | Victoria University of Wellington | New Zealand | Collaborator | 1 December 2018 - 15 December 2018 | UNSW |
| Prof. Ali Yazdani | Princeton University | United States | International Scientific Advisory Committee | 1 December 2018 - 15 December 2018 | Monash, UNSW |
| Prof. Barbaros Oezylmaz | National University of Singapore | Singapore | Partner Investigator | 1 December 2018 - 15 December 2018 | Monash |
| Prof. Victor Galitski | University of Maryland | United States | Partner Investigator | 1 December 2018 - 15 December 2018 | Monash |
| Dr. Bent Weber | Nanyang Technological University | Singapore | Scientific Associate Investigator | 1 December 2018 - 15 December 2018 | Monash |
| Prof. Shaffique Adam | National University of Singapore | Singapore | Scientific Associate Investigator | 1 December 2018 - 15 December 2018 | Monash, UNSW |
| Dr. Luke Fleet | Nature | United Kingdom | Editor | 1 December 2018 - 16 December 2018 | Monash, UNSW |
| Dr. Marcin Syperek | Wrocław University of Science and Technology | Poland | Research Fellow from Partner Organisation | 1 December 2018 - 31 December 2018 | ANU |
| Prof. Suk-Ho Choi | Kyung Hee University | Korea, Republic of | Collaborator | 1 December 2018 - 28 February 2019 | UOW |
| Dr. Luigi Colombo | Texas Instruments / UT Dallas | United States | Advisory Committee | 2 December 2018 - 7 December 2018 | UNSW |
| Prof. Francois Peeters | University of Antwerp | Belgium | Collaborator | 2 December 2018 - 7 December 2018 | UNSW |
| Prof. Uli Zuelicke | Victoria University of Wellington | New Zealand | Collaborator | 2 December 2018 - 7 December 2018 | UNSW |
| Prof. James Hone | Columbia University | United States | Partner Investigator | 9 December 2018 - 15 December 2018 | Monash |
| Prof. Nancy Sandler | Ohio University | United States | Collaborator | 10 December 2018 - 15 December 2018 | Monash |

# VISITS TO PARTNERS

| FLEET TRAVELLER(S) | INSTITUTION | COUNTRY | TRAVEL TYPE | DATES |
|---|---|---|---|---|
| Daisy Qingwen Wang | Nanyang Technological University Singapore | Singapore | ECRs and Students visiting FLEET partners | 3 January 2018 |
| Daisy Qingwen Wang | National University of Singapore | Singapore | ECRs and Students visiting FLEET partners | 3 February 2018 |
| Alex Hamilton | Tsinghua University | China | Chief Investigators visiting FLEET partners | 10 March - 13 March 2018 |
| Nagarajan Valanoor | University of Texas, Austin | United States | Chief Investigators visiting FLEET partners | 12 March 2018 |
| Nagarajan Valanoor | Tsinghua University | China | Chief Investigators visiting FLEET partners | 28 June 2018 |
| Oleg Sushkov | Max Planck Institute for Solid State Physics | Germany | Chief Investigators visiting FLEET partners | 3 July - 17 July 2018 |
| Dimi Culcer | Beijing Computational Science Research Center | China | Chief Investigators visiting FLEET partners | 2 July - 18 July 2018 |
| Kristian Helmerson | Joint Quantum Institute | United States | Chief Investigators visiting FLEET partners | 18 September - 21 September 2018 |
| Kristian Helmerson | Massachusetts Institute of Technology | United States | Chief Investigators visiting FLEET partners | 24 September - 25 September 2018 |
| Kristian Helmerson | University of Colorado Boulder | United States | Chief Investigators visiting FLEET partners | 26 September - 27 September 2018 |
| David Cortie | Australian Nuclear Science and Technology Organisation | Australia | ECRs and Students visiting FLEET partners | 14 October 2018 to 14 January 2019 |
| Dimi Culcer | Beijing Computational Science Research Center | China | Chief Investigators visiting FLEET partners | 16 November - 30 November 2018 |
| Matthias Wurdack | University of Wuerzburg | Germany | ECRs and Students visiting FLEET partners | 22 December 2018 to 20 January 2019 |

See **FLEET.org.au/annual-reports** for

- Boards and committees
- Workshops and seminars
- Media mentions
- Outreach events
- Home science activities

"The scientific themes and approaches within FLEET are well structured and the Centre is showing signs of strong scientific results with some high impact publications."

**Prof Ali Yazdani**
FLEET International Scientific Advisory Committee, Princeton University

## ARTWORK & PHOTOGRAPHER CREDITS

**Barbara Caroline Colling Kuhn** page 82. **Cecilia Bloise** page 75. **Dianne Ruka** page 15, 29, 57, 58, 62, 63, 68, 69, 74, 84-87, 99. **Daniel Sando** page 74. **Dave Wong** page 59. **Einstein a Gogo** page 83. **Elena Ostrovskaya** page 68. **Errol Hunt** page 59. **Fung Lay** page 47. **Grant Turner** page 12, 24, 25, 44, 52, 60, 109. **MacDiarmid Institute** page 55. **Mats Bjorklund** page 14. **Matthew Rendell** page 66. **Michael Fuhrer** page 9, 62, 64. **Paul Dyke** page 36. **RMIT** page 50. **Steve Morton** page 4, 10, 26, 35, 42-43, 49, 76, 78-79. **Tegan Owen** page 70, 72, 76, 77. **Tich-Lam Nguyen** page 38, 56, 59, 69, 73. **Paul Jones** page 84. **Justin Turner** page 41, 86-88, 101.

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

FLEET.org.au
@FLEETCentre
contact@fleet.org.au

School of Physics and Astronomy,
Monash University, Clayton VIC 3800 Australia

Authorised by FLEET Executive Committee, February 2019
**Writing** Errol Hunt, FLEET
**Editing** Margie Beilharz, The Open Desk
**Design** Idaho Design & Communication

## OUR PARTNERS

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