GROUP OF EIGHT AUSTRALIA

Curated:

Go8 Space Summit 2019

THE UNIVERSITY OF WESTERN AUSTRALIA

MONASH University

Australian National University

THE UNIVERSITY of ADELAIDE

THE UNIVERSITY OF MELBOURNE

UNSW

THE UNIVERSITY OF QUEENSLAND AUSTRALIA

THE UNIVERSITY OF SYDNEY

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Introduction

As Group of Eight (Go8) Chief Executive, I take great pride in presenting to you the curated Space Capability of the eight Go8 members. It is being released in conjunction with the "Go8 Space Summit" hosted by Go8 member the Australian National University (ANU) on 13 August 2019.

The Go8 is comprised of Australia's leading research-intensive universities. Seven of our eight members are ranked in the world's top 100 universities – no mean feat in a nation of just 25 million people. Only the US and the UK, on a per capita basis, can best this result.

Over 99 per cent of the Go8's research is ranked as world class or above. While research is at our heart, we are far more. With an ethos of quality and a commitment to excellence, we deliver Australia some 100,000 quality graduates each year; the leaders of tomorrow.

The Space sector in Australia is an inspiration, a key component of the global Space economy, and described both as mature and revitalised, and therefore as a defining domain in coming decades. To the Go8 it is

The Go8 recognises that we have, with us and before us, many ethical, legal and security implications associated with the Space sector. Go8 expertise is eminently positioned to assist manage these.

clearly both. It is mature in the sense we are proud to have been involved for many years. It is revitalised because we are also proud to now find ourselves at the heart of a sector making a significant global mark in the 21st Century.

The Go8 has much to offer the sector, and we work assiduously to ensure we are invaluable research partners for and with Government and industry. It is our dedicated goal to ensure Australia can reap benefits from every opportunity.

This is also applicable to the skills the Space sector must have. As our Minister for Industry, Science and Technology Hon Karen Andrews MP told Parliament on 22 July "Space has long been called the final frontier, but under the Morrison Government, Space is the new jobs frontier."

It is important to note in this foreword that the Go8 understands how much is required of us in so many areas of this sector. Skills are obviously critical and we also recognise for example, that we have already with us, and yet to come, many ethical, legal and security implications associated with the Space sector. Go8 expertise is eminently positioned to assist manage these.

The Go8 is not reticent to say we are home to the best, and proud to be so. Being the best, striving never to be anything less has enabled the Go8 to build solid national and International partnerships, and problem solving and advisory relationships around the world with Governments and industry.

This curated capability statement sets out who within the Go8 can help you, and what we do. It is the third in an ongoing series of Go8 capability statements. The Go8 has previously released Genomics and Defence capability statements.

Vicki Thomson
Go8 Chief Executive

The University of Adelaide

The University of Adelaide contact point:

Professor Michael Webb
Director, Defence, Cyber and Space

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Skills and capability

The University of Adelaide has had over 50 years of space research and development with broad interdisciplinary capabilities.

In 1967, the University of Adelaide partnered with the Weapons Research Establishment (WRE) in the development and launching of WRESAT (Weapons Research Establishment Satellite), Australia's first satellite. The university then continued to undertake research in areas of direct relevance to the space sector including advanced sensing, photonics, radar and communications.

Currently the university's involvement in the space sector includes many areas of science, technology, health, policy and practice. This expertise includes:

- scientists working on advanced technology, including radar, space situational awareness and cryogenic sapphire clocks
- mathematicians and computer scientists analysing large data sets through machine learning, advanced statistics, and optimisation

- engineers focusing on designing and integrating nanosatellites, communication networks, autonomous systems, and advanced materials
- medical scientists investigating and advancing aerospace medicine education
- practice lawyers and policy researchers looking at contemporary challenges in global security, and military and space law.

The university works with the Department of Defence, Defence Science and Technology (DST) Group, Space Industry and the SA Government to ensure the university's innovations meet real end user needs, and that pathways to commercialisation are identified.

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Current research projects and programs are directly addressing the current challenges faced by the space sector and its vast service network, from deep-space sensing to satellite systems and terrestrial support.

Research strengths

Space Situational Awareness (SSA)

This research is focused on developing new and novel algorithms, inspired by AI and space-based computational platforms, to detect, map and track resident space objects (RSO).

High-Speed Space-Based Positioning and Navigation

Researchers are developing algorithms for event sensors and smart cameras to realise low-power/high-efficiency space-based capabilities including attitude estimation, positioning, simultaneous localisation and mapping, and 3D reconstruction.

The University of Adelaide

Multi-Sensor Platform for SSA

This project is developing a multisensory platform consisting of optical and RF sensors to provide highly accurate SSA and extremely low latency satellite internet.

Earth Observation (EO) analytics using modern machine learning

Developing deep learning-based and graphics processing unit (GPU) enabled algorithms that can detect and count objects in space, perform instance-level and semantic segmentation, and generate 3D reconstructions and analyses of satellite imagery.

Space Chemistry – Guardian satellite-based flow-chemistry system

This uses a specialised flow-chemistry system designed to produce quantum dots in zero gravity, in a range of sizes and in near-real time. These dots can be manufactured to produce a range of spectral signatures that could act as decoys for potential attacks.

Space Processing – Resource Upgrade in the Chain of Space Mining

Investigating potential off-world mining processes including adjacent metal separation from mimicked

asteroid ores through continuous-flow solvent extraction. Research is also investigating phosphorous mining from mimicked moon crust minerals utilising continuous-flow solid-solvent extraction.

High-energy astrophysics

The High-Energy Astrophysics group studies some of the Universe's most energetic processes by observing neutrinos, very-high-energy gamma rays and ultra-energetic cosmic rays. It also carries out work in the optical, radio and X-ray regions of the electromagnetic spectrum. The group is involved in many large-scale international collaborations, including the:

- Cherenkov Telescope Array, and High Energy Stereoscopic System (gamma rays)
- IceCube Neutrino Observatory (neutrinos)
- Pierre Auger Observatory (cosmic rays).

Atmospheric physics

The Atmospheric Physics group is involved in all aspects of the atmosphere's and ionosphere's physics, up to altitudes near 100 km. It develops and exploits new methods for atmospheric remote sensing, using radar, passive and active optical techniques, and GPS and other satellite techniques. The group's research has explored:

- meteoroid fragmentation, using radio holography
- GPS measurements for ground and space
- turbulence and radio-wave scatters in the lower atmosphere, using radar
- atmospheric radar imaging and interferometry
- measurement for climate and meteorological numerical models.

Miniaturised Orbital Electronic Sensor System (MOESS)

This Defence Innovation Partnerships project, in collaboration with DEWC Systems, is working to develop a small electromagnetic sensor system for space-based intelligence, surveillance and reconnaissance.

Advanced Microelectronics for Space Applications

New, high performance sensing and microelectronic systems are being developed for use in a range of integrated circuit technologies – including complementary metal–oxide–semiconductor (CMOS), silicon-on-insulator (SOI), gallium-arsenide (GaAs) and gallium nitride (GaN) technologies – for space applications. These new systems have specific focus on the optimisation of size, weigh, power and performance in the space environment.

Nanosatellite Technologies – CubeSat Design

The design, building and testing of a functional three-unit CubeSat with the capacity for multiple payloads. These CubeSats are being designed with launch-ready qualifications for rapid deployment and operation.

Research infrastructure

In partnership with Government and industry the university has established a number of world-class research institutes and centres to tackle state and national research priorities. Research infrastructure includes:

- The Institute for Photonics and Advanced Sensing (IPAS) with capabilities in the design, fabrication and implementation of disruptive measurement technologies
- OptofabNode, an Australian National Fabrication Facility – the leading specialty glass and optical fibre fabrication facility in Australia for sensing and fibre laser applications
- The Prescott Environmental Luminescence Laboratory with world-leading radiation detection and measurement capabilities for population radiation exposure, and forensic analysis of clandestine radiological sites
- The Australian Institute for Machine Learning infrastructure, e.g. Visual Simultaneous Localisation and Mapping (VSLAM)
- The Applied Electromagnetics Group maintains an electromagnetic anechoic chamber and instrumentation to support research

in transformative products and services, including antennas and systems for defence applications, high-speed next-generation wireless communications, and high-resolution 'see through' radar imaging

sector and has a range of flexible approaches to engagement. The university has invested in several strategic partnerships around research and education and looks forward to a close relationship with the Australian Space Agency to

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- High-Performance Computing with a 'Phoenix' supercomputer with storage capacity of 700 terabytes and processing speed up to 450 teraflops
- A high-quality observatory that contains a large and efficient SBIG ST-9 CCD (charge-coupled device) camera, and a Shelyak LHIRES (Littrow High Resolution) III spectrograph.

Collaborations

The University of Adelaide is committed to partnering with government and industry in the space

be located at Lot 14, immediately adjacent to the university.

SmartSat Cooperative Research Centre (CRC)

The University of Adelaide is a key participant within the newly announced SmartSat CRC. Key capabilities being applied to the SmartSat research programs include:

- Machine learning and Artificial Intelligence (AI) for SmartSat systems
- Space law, policy and governance
- Cybersecurity in space operations
- Advanced satellite communications,

The University of Adelaide

including antenna design and signal processing

- Space microreactors for space manufacturing
- Spatial Sciences – landscape-scale understanding, management and monitoring of terrestrial, aquatic and marine environments, and natural and managed agri-ecosystems.

The Woomera Manual on the International Law of Military Space Operations

The university together with UNSW, the University of Exeter, and University of Nebraska College of Law, is drafting The Woomera Manual on the International Law of Military Space Operations, which will become the definitive document on military, commercial uses and security law as it applies to space.

Gravitational waves and extreme physics

The university is a partner in the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav). This centre will capitalise on the historic first detections of gravitational waves to understand the extreme physics of black holes and warped spacetime.

Key personnel

Faculty of Engineering Computer and Mathematical Sciences

Associate Professor Tat-Jun Chin

Computer vision (space situational awareness)

Dr Hung Nguyen

Network engineering

Professor Volker Hessel

Pharmaceutical engineering and space processing

Professor Michael Goodsite

Environmental engineering

Associate Professor Maziar Arjomandi

Aerospace engineering

Dr Nataliia Sergiienko

Aerospace engineering

Professor Ian Reid

Robotic vision

Professor Anton van den Hengel

Machine learning

Professor Ali Babar

Secure software engineering

THE UNIVERSITY of ADELAIDE

Associate Professor Zeyad Alwahabi

Laser diagnostics; laser spectroscopy

Associate Professor Phillip Visintin

High performance concrete for launch and landing pads

Professor Christophe Fumeaux

Antenna Desi

Dr Withawat Withayachumnankul

Terahertz Engineering

Dr Said Al-Sarawi

Micro-electronics

Dr Matthew Sorell

Space cybersecurity

Professor Cheng-Chew Lim

Guidance, launch & control with genetic fuzzy inference systems

Faculty of Health and Medical Sciences

Associate Professor Anna Ma-Wyatt

Human factors

Faculty of Sciences

Professor Sandy Steacy

Space engagement

Professor Megan Lewis

Environmental earth observation & spatial sciences

Professor Nigel Spooner

Radiation sensing

Professor Andre Luiten

Advanced sensing and photonics

Associate Professor Andrew MacKinnon

Atmospheric physics

Dr Dorothy Turner

Earth observation and spatial sciences

Associate Professor Bertram Ostendorf

Geospatial sciences and earth observation

Professor Peter Veitch

Next generation of gravitational wave detectors, photonics

Dr Kenneth Clarke

Earth observation and spatial sciences

Professor David Ottaway

LIGO gravitational wave detectors, atmospheric characterisation

Dr Ramesh Raja Segaran

Unmanned aerial vehicles, earth observation, spatial sciences

Faculty of the Professions

Professor Melissa de Zwart

Space law

Professor Dale Stephens

Space law

The Australian National University (ANU)

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Professor Anna Moore
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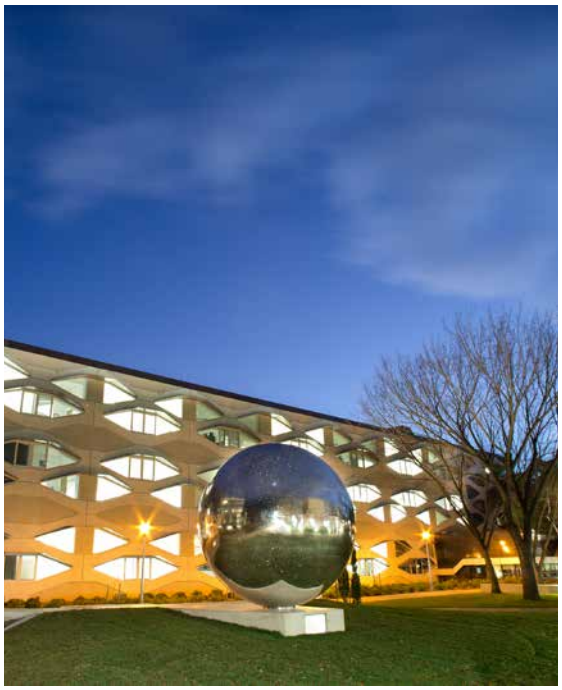

Skills and capability

The Australian National University (ANU) has a long history in space-related research. Recent leading-edge university research and development (R&D) efforts include secure optical communications, space situational awareness, space debris tracking, laser-based metrology and control systems, vacuum technologies, plasma thrusters, data analytics for Earth Observations, infra-red optical instrumentation, payload fabrication and testing.

The university is home to the Advanced Instrumentation and Technology Centre (AITC), the National Space Test Facility (NSTF) and Siding Spring Observatory located in Coonabarabran, NSW.

The university also has world-class expertise in medical and health sciences, defence strategy and legal studies, particularly international law, economics and business.

The university has a proven track record in transferring new technologies to the market. Successful companies such as Lithicon, Quintessence Labs and Liquid Instruments have survived

Australian National University

the 'valley of death' to become leaders in their areas.

To position the university as a significant player in developing sovereign Australian capability in space, an innovation institute dedicated to space research and commercialisation was launched in October 2018. The ANU Institute for Space – InSpace focuses all of the university's space expertise, capabilities and relationships to be a crucial point and leader in the national space industry.

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Research strengths

ANU boasts several areas of strength in Space Research, including:

- Space Instrumentation and Sensors
- Earth Observation services and data analytics
- AgriTech
- Planetary science
- Space Situational Awareness (SSA) and debris monitoring
- Propulsion, Plasma Thrusters
- Vacuum, Radiofrequency, Plasmawind tunnels, plasma sensors and probes
- Laser Communications Technologies, services and ground stations
- Quantum Communications
- Metrology
- Unmanned Aerial Vehicles (UAV) and Cubesats
- Artificial Intelligence, Machine Learning and Onboard Processing
- Assembly Integration and Testing
- Advanced Manufacturing
- Space Medicine, MedTech and Psychology
- Space Law and Policy.

Examples of initiatives deriving from these areas of expertise are:

Gravity Recovery and Climate Experiment Mission (GRACE)

Professor Paul Tregoning, Research School of Earth Sciences and Professor Daniel Shaddock, Research School of Physical Sciences

NASA's Gravity Recovery and Climate Experiment (GRACE) missions, have been incredibly successful. ANU researchers in physics and earth science have developed hardware for laser-ranging and software to process the first publicly available data from the satellites and track water availability on earth.

Plasma propulsion thruster (Pocket Rocket)

Professor Christine Charles, Research School of Physics and Engineering

To assist with orbit boosting and attitude control of CubeSats, micro-propulsion systems are required, but are currently limited. The university is developing a potential electrothermal plasma micro-thruster for use with CubeSats or other micro-satellites: the Pocket Rocket.

Quantum Laser Communications Technologies

Dr Francis Bennet, AITC and Professor Ping Koy Lam, Research School of Physics and Engineering

Quantum Laser communications is the latest space communications technology, able to provide secured data transfer rates significantly higher than current radio frequency systems.

This technology delivers data transmissions of superior security and range, for advanced satellite experiments and deep space exploration.

Infra-red Technologies

Dr Rob Sharp and Dr Jamie Gilbert, AITC

Emerging noise-free infrared detector technology offers exciting new opportunities in collecting and analysing data from space, to help solve complex problems on the ground (in defence, agriculture, mining and ecology). Using satellite-mounted spectrographs, we can turn our attention back to earth to analyse our oceans, waterways, crops, vegetation, soil and minerals, or urban infrastructure.

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Space Health and Medicine
Professor Russell Gruen

ANU has wide expertise in the area and focuses on modelling and simulation of human physiology and psychology in space environments, with a view to developing research and training opportunities. This includes: minimising human radiation exposure, computer modelling of the cardiorespiratory system in reduced and microgravity, the psychology of strengthening teams for spaceflight missions.

Research infrastructure

AITC

- The Advanced Instrumentation and Technology Centre (AITC) offers specialist engineering environments, outstanding technical capabilities in optics, mechanical and systems engineering, software controls, and data collection and analysis. AITC provides increased capability in the development of high-performance instrumentation, precision manufacturing, rapid prototyping and the test and evaluation of small spacecraft.

- The AITC is a key national resource for Australia's space industry (including startups and larger companies), providing increased capability in the development of high-performance instrumentation, precision manufacturing, rapid prototyping and the test and evaluation of small spacecraft. The AITC has a long history of research and development in astronomical instrumentation, but also has considerable expertise and experience in design and development of advanced instrumentation for space science (for example, Space Situation Awareness or SSA).
- The Centre completed two instruments for the twin eight-metre telescopes of the Gemini Observatory: the Near-infrared Integral-Field Spectrometer (NIFS) and Gemini South Adaptive Optics Imager (GSAOI), in addition to instrumentation for the facilities of Mt Stromlo Observatory and Siding Spring Observatory: such as the Dual-Beam Spectrograph (DBS), and Wide-Field Spectrograph (WiFeS) instruments for ANU 2.3 metre telescope (also built largely in-house), and the wide-field, 238 megapixel SkyMapper camera.
- ANU, through AITC, leads Australia's involvement in the Giant Magellan (GMT). The university will deliver a back-end spectrograph and adaptive-optics solutions for the project, which will be the world's largest and most powerful telescope when it is completed in 2024.

Space Test Facility

- The ANU has the only facility in Australia that enables end-to-end engineering from initial design to the launch pad.

National Computational Infrastructure (NCI)

- NCI is home to the Southern Hemisphere's fastest supercomputer. It is supported by the Australian Government's National Collaborative Research Infrastructure Strategy (NCRIS), with operational funding provided through a formal collaboration incorporating CSIRO, the Bureau of Meteorology, ANU, Geoscience

Australia, the Australian Research Council, and a number of research-intensive universities and medical research institutes.

- The NCI is the regional repository for the southeast Asian set of the European Commission's Copernicus Earth[1] observation data. The regional Copernicus data hub, managed by Geoscience Australia for the Australian Government, will include satellite data covering sea temperature, atmospheric composition, vegetation health and many other environmental variables. Through the Copernicus Regional Data Hub there will be access to high-resolution, timely data products. The increased coverage, resolution and variety of the earth observations will open up many possibilities for research, policy and industrial uses[2].

Australian National Fabrication Facility (ANFF)

- Established under the NCRIS program, the ANFF provides researchers and industry with access to state-of-the-art fabrication capabilities through a network of eight nodes including 21 institutions. The facilities are based on photonic and electronic materials growth, processing and fabrication of devices including micro electro mechanical systems (MEMS). These facilities provide a range of capabilities and services for the micro and nanofabrication of photonic and related devices as well as the fabrication of waveguides and photonic crystals.

1 The Copernicus program collects vast amounts of global data from the European Space Agency (ESA) and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)'s Sentinel satellites, a growing fleet orbiting the Earth and capturing new measurements every day. This data is then stored, analysed and distributed for a wide range of applications such as environmental protection, sustainable resource development, climate change mitigation and managing risks and emergency response for natural disasters.

2 https://nci.org.au/services/nci-national-research-data-collection/earth-observation/copernicus-regional-data-hub/

Collaborations

The University has built collaborative international partnerships with agencies including NASA, the European Space Agency, CNES, DLR, JAXA, and has close collaboration with national and international aerospace companies.

ANU is also home to a $20 million CRC which is tracking and cleaning up hundreds of thousands of pieces of space debris which orbit Earth and pose serious risks of collision with satellites, space stations and other space craft. Project partners include EOS Space System, Lockheed Martin, NASA Ames Research Centre, Japan's National Institute of Information and Communications, Optus and RMIT. Also, as a core partner in SmartSat ANU's InSpace institute will play a major role in the biggest space industry R&D collaboration in Australia's history. Launched in April 2019 and led by the University of South Australia (UniSA), the SmartSat CRC brings together nearly 100 partners and international collaborators. With significant investment by the Australian Government, the combined commitment to the CRC is $245 million.

ANU is also a member of the Australian Optical Communications Ground Station network, This initiative is in partnership with UNSW, University of Western Australia, UniSA, CSIRO, Defence Science Technology (DST), University of Auckland, industry partners and international members. Laser communications is the latest space communications technology, able to provide data rates as much as a hundred times higher than current systems. In order to develop this ground-breaking technology, a national network of ground stations for laser communications is the first step to establishing Australia as a leading provider of secure satellite links for a large and growing market.

The University also collaborates on the QUOLLSat Mission. This mission aims to develop technology which enables a global quantum secure network with commercial applications, and is in partnership with DLR-German Aerospace Centre, CSIRO, Tesat, NASA Jet Propulsion Laboratory, DST and the Japanese National Institute of Information and Communications Technology (NICT).

Australian National University

Key personnel

Professor Anna Moore
– Director AITC and InSpace

Professor Sally Wheeler
– Dean College of Law

International and Space Law

Professor Elanor Huntington
– Dean College of Engineering and Computer Science

Quantum Cybernetics, Optical Devices

Professor Tim Senden
– Director Research School of Physics and Engineering

Imaging Technology for Oil and Gas Exploration

Professor Paul Tregoning
– Associate Director and Head, Earth Dynamics, Research School of Earth Sciences

Photogrammetry and Remote Sensing, Surfacewater Hydrology, Environmental Science and Management

Dr Marta Yebra – Fenner School of Environment and Society

Environmental Monitoring, Natural Hazards, Photogrammetry and Remote Sensing Quantum Cybernetics, Optical Devices

Professor Christine Charles
– Head of the Space Plasma, Power and Propulsion laboratory

Research School of Physics and Engineering
Plasma Physics, Fusion Plasmas; Electrical Discharges, Aerospace Engineering, Astronomical and Space Sciences

Professor Daniel Shaddock –
Group Lead, Space Instrumentation

Research School of Physics and Engineering – Precision measurements using laser interferometry

Dr Francis Bennet –
Research School of Astronomy and Astrophysics, AITC

Lasers and Quantum Electronics, Classical and Physical Optics, Astronomical and Space Instrumentation

Professor Ping Koy Lam –
Research School of Physics and Engineering

Quantum Optics, Quantum Information

Dr Rob Sharp – Research School of Astronomy and Astrophysics, AITC

Infrared detector technology

Dr Jamie Gilbert – Project Engineer, Research School of Astronomy and Astrophysics, AITC

Imaging, metrology, micro-positioning, multi-object spectroscopy, opto-mechanics, actuators and sensors

Professor Russell Gruen – Dean of the College of Health and Medicine

Space Health and Medicine

The University of Melbourne

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Associate Professor Michele Trenti
School of Physics

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Skills and capability

The University of Melbourne is engaged in a wide range of multi-disciplinary space science and space technology projects, including fundamental research in astronomy and Earth sciences utilising satellite observations; development of innovative data analytics techniques for digital agriculture; collaborations with industry partners focused on next-generation space-ready materials, sensors and radiation hardened electronics.

The university is leading an international space project to design, fabricate and operate the world's first actively cooled infrared space telescope hosted on a nanosatellite, developing leap-frogging technological innovation to augment national space capabilities, and collaborating with prominent aerospace research centers in the United States and Europe.

Its researchers are at the forefront of development of custom-designed advanced components for satellites and hypersonic vehicles and have extensive expertise to handle

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challenging signal processing and analysis across the electromagnetic spectrum.

Research strengths

The university's research has a strong track record of impact in aerospace and computational fluid dynamics, satellite data processing and analysis, applications to astrophysics and Earth observations. Areas of emerging strength and investment associated with the growth of the national space sector are development and optimisation of spacecraft concepts, as well as design and fabrication of advanced materials, sensors, and electronics.

The university space research portfolio includes a breadth of insight and expertise to analyse effectively satellite data for innovative applications, to assess feasibility, and to conceptualise solutions for mission design, and provide customised space-ready hardware to meet research and industry needs.

The portfolio includes:

Infrared Nanosatellites
Associate Professor Michele Trenti

Nanosatellite mission design, spacecraft thermal modeling, image processing, simulations of satellite-ground segment communications.

The university is leading an international space project to design, fabricate and operate the world's first actively cooled infrared space telescope hosted on a nanosatellite ...

Space qualification of miniaturised cryocoolers, deployable thermal radiators.

Radiation Hardened Electronics
Professor Elisabetta Barberio

Low-power, ultra-small associative memories and radiation hardened CMOS electronics for satellite and medical applications. Design, characterisation, and testing of custom radiation hardened componentry.

The University of Melbourne

Spacecraft Optimisation
Dr Airlie Chapman

Advanced spacecraft optimisation through multi-agent dynamics, networked dynamic systems, data-driven control and graph theory.

Advanced Materials
Professor George V Franks

Novel materials for hypersonic platforms and aerospace applications including advanced composites, metals and polymers, in particular ultra-high temperature ceramics and low thermal expansion ceramics.

Atmospheric and Earth Observations
Professor Peter Rayner

Statistical inference and data assimilation applied to biogeochemistry. Satellite-based carbon dioxide measurements, spectrometers for atmospheric composition characterisation. Climate modelling.

Digital Agriculture
Associate Professor Sigfredo Fuentes

Satellite and unmanned aerial vehicle remote sensing applied to agriculture. Advanced analytical platforms (machine learning and Artificial Intelligence) for plant physiology, climate change, sensory technologies and robotics.

Solar Cells
Professor David Jones

Advanced organic semiconductors for use in printed electronics, thin-film solar cells, characterisation of thin films and photovoltaic devices, solar simulations.

Aerospace Research
Professor Ivan Marusic

Drag reduction, acoustic modelling and testing, turbulence modelling, computational fluid dynamics modelling and high Reynolds number experimental facilities.

Sensor and Signal Processing
Professor Bill Moran

Sensor design, tracking, detection, matched filtering, optimal signal processing, dynamic stochastic control and networked sensor systems. Dynamic resource allocation and sensor scheduling.

Multi-wavelength Data Analytics
Professor Rachel Webster

Multi-wavelength (radio to x-ray) data processing and analysis, data mining, pattern recognition.

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Research infrastructure

- Clean room complex, equipped with advanced instrumentation for materials fabrication, characterisation and analysis, and vacuum chambers
- High Reynolds number wind tunnel
- Science Faculty Technical Workshop, comprising both Mechanical and Electronics, offering specialised facilities as well as technical and engineering support for development of custom-designed components
- Ceramic powder facility for 3D printing and near-net-shape processing for production of ceramic components for aerospace applications
- High-performance computing infrastructure for advanced data mining, data analysis, optimisation problems, numerical solutions of aerodynamics and thermal models.

Collaborations

The university has strong strategic collaborations with national and international research partners, as well as with aerospace companies.

The university is leading the international SkyHopper Space Telescope mission, which includes as partners four other Go8 universities, the NASA Goddard Space Flight Center, the Max Planck Institute for Extraterrestrial Physics, and the Italian National Institute of Astrophysics.

Other national and international partnerships include:

- European Organisation for nuclear research (CERN): Radiation hardened electronics
- Treasury Wines: Digital agriculture
- Lockheed Martin and US Office of Naval Research: Ceramic material development
- Australian Defence Science and Technology: Research programs in several areas.

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The university is a node of multiple research networks, including the Centre of Excellence for All-Sky Astrophysics in 3-Dimensions, the Australian Centre for Advanced Photovoltaics, and the Defence Cooperative Research Centre in Trusted Autonomous Systems.

Professor David Jones

Solar Cells Research Leader

Professor Ivan Marusic

Aerospace Research Leader, Deputy Dean Research, Melbourne School of Engineering

Professor Bill Moran

Sensor and Signal Processing Research Leader

The university is leading the international SkyHopper Space Telescope mission, which includes as partners four other Go8 universities, the NASA Goddard Space Flight Center, the Max Planck Institute for Extraterrestrial Physics, and the Italian National Institute of Astrophysics.

Key personnel

Associate Professor Michele Trenti

Infrared Nanosatellites Research Leader

Professor Elisabetta Barberio

Radiation Hardened Electronics Research Leader

Dr Airlie Chapman

Spacecraft Optimisation Research Leader

Professor George V Franks

Advanced Materials Research Leader

Associate Professor Sigfredo Fuentes

Digital Agriculture Research Leader

Professor Peter Rayner

Atmospheric and Earth Observations Research Leader

Professor Graham Schaffer

Multidisciplinary materials

Dr. Jafar Shojaii

Radiation Hardened and Low Power Electronics

Dr. Shane Usher

Space Analogue Facilities

Professor Rachel Webster

Multi-wavelength Data Analytics Leader

Monash University

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Skills and capability

Monash has broad research capability relevant to the space sector; capability that is both world-leading and deeply collaborative. In the upstream domain, Monash is best-in-field in advanced and additive manufacturing for aerospace, including metal 3D printing, composite and polymer structures, and micro and nano fabrication.

Monash engineers have significant expertise in aerodynamics and gas dynamics, relevant to both launch and re-entry. Monash also hosts world-leading research centres in low-energy electronics, fuel cell technologies, radio frequency (RF) and visible light communication. Automation, autonomous flight and robotics are also core capabilities that the university is focused on further enhancing.

In the space science and earth-observation domain, Monash also has built extensive capability. The university collaborates with European Space Agency (ESA) and NASA on soil moisture Earth-observation missions, and the tracking of space debris and meteorites.

MONASH University

Monash astrophysicists work with data from NASA, ESA and Japan Aerospace Exploration Agency (JAXA) satellites and observatories in the study of the sun and other stars and galaxies. The university also has significant capability in data encryption, analysis and management. This capability is currently being utilised by the French Space Agency CNES, and NASA.

Research strengths

Advanced Manufacturing

Professor Xinhua Wu is a global leader in additive manufacturing for aerospace components, an area in which Monash has an excellent concentration of expertise, including the spin-out company Amaero. Teams based at Monash produced the first 3D printed aerospike rocket nozzle and 3D printed jet engine.

Professor Bijan Shirinzadeh specialises in autonomous control for both composite manufacturing systems and airborne platforms.

Professor Adrian Neild and Professor Wenhui Duan are world leaders in micro and nano scale manufacture respectively, an area of growing importance given the market penetration of cube, micro and nano satellites.

Monash is the sole academic sponsor of Women in Aviation/Aerospace Australia, seeking to strengthen the aerospace field by increasing its diversity.

Monash University is also a key part of the supply pipeline for the space industry, being one of five Group of Eight (Go8) Universities with an undergraduate aerospace engineering degree. As well as curricular activities, Monash has highly successful student teams competing in rocketry, autonomous flight and Martian rover design.

Monash is the sole academic sponsor of Women in Aviation/ Aerospace Australia, seeking to strengthen the aerospace field by increasing its diversity.

Monash University

Professor Tanja Junkers and Professor San Thang develop novel polymer materials with a range of applications to space systems.

Launch system and satellite technologies

Dr Daniel Edgington-Mitchell, Professor Damon Honnery and Professor Julio Soria work with international partners in the United States and Europe on pulsed/rotating detonation engines, advanced nozzle design, thrust vectoring and hybrid rocket combustion.

Professor Yi-Bing Cheng, Professor Udo Bach and Professor Leone Spiccia are developing printable solar cell technology, while Professor Doug MacFarlane is a world leader in fuel-cell technology.

Communication and data security

Professor Michael Fuhrer and Associate Professor Qiaoliang Bao develop novel low-energy communication and sensing technology ideal for the space environment. Professor Jean Armstrong is a world leader in RF and visible-light communication systems. Associate Professor Carston Rudolph at the *Monash Cybersecurity Lab* specialises in encryption and protection of communication systems.

Remote observation

Professor Geoff Webb and Dr Francois Petitjean in the *Monash Centre for Data Science* work with the French Space Agency in Earth Observation Data Analytics, focusing on processing and interrogating large observational databases.

Professor Jeffrey Walker in Civil Engineering received the Anton Hales Medal from the AAS for his work with NASA and ESA developing soil-moisture monitoring missions.

Space Science

The *Monash Centre for Astrophysics* includes the *Solar Physics Research Group*, where Professor Paul Cally and Dr Alina Donea have made a number of significant discoveries related to helioseismology and “sunquakes”. The *Monash Gravitational-Wave Group* contributed to the first direct detection of gravitational waves; Monash astrophysics expertise ranges from the planetary to the galactic scale.

Research infrastructure

Monash is host to ARC Centres of Excellence and Industry Hubs with research capability relevant to the space domain:

- These include the ARC Centre of Excellence in Future Low-Energy Electronics Technologies, where novel 2D materials, low-power optical communications, graphene detectors and other technologies are being developed.
- Monash also hosts the ARC Research Hub for Transforming Australia's Manufacturing Industry through High Value Additive Manufacturing; a major component of which is the Monash Centre for Additive Manufacturing (MCAM). MCAM has one of the largest concentrations of metal 3D printing equipment in Australia, including selective laser melting, direct laser deposition and hot isostatic press systems.
- The ARC Industrial Transformation Research Hub for Nanoscience-based Construction Material Manufacturing is also headquartered at Monash; the hub includes a large team of researchers developing bespoke construction materials.

Monash University

There are major research platforms at Monash:

- The Monash Centre for Electron Microscopy is one of the nodes of the Melbourne Centre for Nanofabrication, Australia's leading facility for micro/nano fabrication.
- The Monash Immersive Visualisation Platform, which includes the CAVE2 facility, provides a unique means to interrogate large datasets.
- The Monash Wind Tunnel is the largest such facility in the Southern Hemisphere, permitting aerodynamic testing at a scale not available elsewhere.
- The Monash X-ray platform has a range of laboratory-scale x-ray systems for the characterisation of materials and specimens, complimenting the nearby Australian Synchrotron.
- Monash hosts MASSIVE, the Multi-modal Australian ScienceS Imaging and Visualisation Environment, a high-performance data processing facility specialising in imaging and visualisation of large datasets.

Melbourne hosts specialised laboratories that have unique research infrastructure:

- The Laboratory for Turbulence Research in Aerospace and Combustion contains supersonic jet, supersonic tunnel, wind tunnel and shock tube facilities dedicated to high-speed flow research.
- The Robotics and Mechatronics Research Laboratory has a range of haptic and autonomous systems for both aerospace vehicles and manufacturing processes. The Laboratory for Microsystems is a nexus of expertise in manufacturing of micro and nanoscale components.

The university has a number of research institutes:

- One such institute, the Monash Energy Materials and Systems Institute, hosts laboratories working on energy production and storage, including the Solar Fuels Laboratory.

Collaborations

Monash University places great value in collaboration with both local industry and international partners. The university has a long history of translating academic output into social and economic impact. Researchers at Monash collaborate closely with international companies, government bodies, and other universities.

In the space domain, researchers in civil engineering collaborate with all the major space agencies on earth-observation and environmental sensing missions.

Researchers in aerospace engineering collaborate with the Technical University of Berlin, Stanford University and CNRS (the French National Centre for Scientific Research) on advanced propulsion concepts.

The Solar Physics group in the School of Mathematics regularly uses solar data from satellites including the Solar Dynamics Observatory, STEREO A and B, Hinode, Japan Aerospace Exploration Agency Solar mission, IRIS, Interface Region Imaging Spectrograph, RHESSI X ray satellite and GOES satellite.

Monash researchers were part of the Laser Interferometer Gravitational-Wave Observatory (LIGO) collaboration that resulted in the detection of gravity waves.

Monash researchers were part of the Laser Interferometer Gravitational-Wave Observatory (LIGO) collaboration that resulted in the detection of gravity waves.

Researchers in Earth, Atmosphere and the Environment are part of the Desert Fireball Network and the Solar System Exploration Research Virtual Institute at NASA, through which they work with scientists at NASA.

The Monash Centre for Data Science works closely with the French Space Agency CNES in Earth Observation Data Analytics.

MONASH University

Key personnel

Professor Marc Parlange,
Provost of Monash University
(and engineer)

Professor Elizabeth Croft,
Dean of Engineering

Professor Chris Davies,
Head of Mechanical and
Aerospace Engineering

Professor Xinhua Wu

Additive manufacturing

Professor Jeffrey Walker

Earth observation

Dr Jasmina Lazendic-Galloway

Astrophysics (supernovas) & space education

Professor Doug MacFarlane

Fuel cells

Professor Tanja Junkers

Polymer materials

Associate Professor
Duncan Galloway

Gravity waves

Professor Jean Armstrong

RF and optical communication

Professor Geoff Webb

Data analytics

Dr Alina Donea

Helioseismology

Associate Professor
Carsten Rudolph

Encryption and data security

UNSW

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Skills and capability

UNSW has a world-leading team of academic and professional staff located across its Sydney and Canberra campuses with capabilities, experience and facilities to deliver space education, research and end-to-end space mission capability.

UNSW offers a range of tailored intensive short courses to meet organisations' capability needs, and specialised undergraduate and postgraduate programs in all aspects of space operations and engineering.

The university is enabling the development of new spacecraft and related technologies and, in turn, contributing to meeting Australia's (and the international community's) need for safe and secure access to space-based technologies for strategic, economic and social benefit and has skills and capabilities in space technology development and engineering, satellite formation flying, advanced instrumentation, space situational awareness (SSA), space ethics and law, and space navigation.

UNSW Canberra Space has the leading space mission capability in

Australia with substantial experience in conceptualising, designing, engineering and operating space missions including the Buccaneer mission in collaboration with Defence Science and Technology Group and multiple cubesat missions with the Royal Australian Air Force. These missions play a role in growing Australia's space experience and contribution and building a skilled space workforce.

Research strengths

Space technology development

UNSW is developing technologies to enable Earth and space observation, analysis and measurement including:

- in-orbit propulsion
- in-orbit thermal control techniques, materials, methods and devices; and
- thermal interactions in exploration vehicles in extra-terrestrial planetary environments.

Satellite formation flying

Control techniques, methods and devices to enable small satellite formations with sensors distributed across multiple platforms to support remote sensing, space situational awareness, astronomy, space science, and other activities. This capability means greater functionality and agility can be achieved at a fraction of the cost of traditional large satellite platforms.

Advanced instrumentation

A range of advanced ground and space-based instruments including:

- Space-based instrumentation: diode laser sensors, the application of electron beam spectroscopy to in-orbit density measurements and advanced imaging and remote sensing systems
- Ground-based optical research telescope applications: extending optical telescopes' capabilities for surveillance and tracking of objects in geostationary and low earth orbit; developing tasking and handover of space objects from one telescope to the next across a network or across ground-based sensors; and measuring light curves
- Ground-based passive radar: development of passive radar for space surveillance, particularly where the total power radiated by space-based emitters is low

UNSW

Space situational awareness (SSA)

Conducting multidisciplinary SSA research combining optical space surveillance, astrodynamics, space physics and machine learning to mitigate risks associated with orbital collisions, particularly with space debris in congested near-Earth orbits.

Space ethics and law

The Australian Centre for the Study of Armed Conflict and Society at UNSW Canberra has deep space law knowledge and is a founding member and key contributor to the Woomera Manual, an international research project (that includes Go8 member the University of Adelaide) to articulate and clarify existing international law applicable to space operations. UNSW is also invested in space ethics including identifying the future problems that advances in space research might create and their potential solutions.

Satellite navigation

The university has more than 30 years' experience in GPS and other Global Navigation Satellite Systems (GNSS) receiver design and signal processing, including interference detection and mitigation, use of signals for remote sensing on both spacecraft and aircraft, and integration with other sensors.

Off-Earth mining

The Australian Centre for Space Engineering Research (ACSER) investigates issues associated with off-Earth mining including environmental impacts, mission design, prospecting methods, mining methods and transport methods.

Research infrastructure

UNSW has a range of facilities relevant to space research including the Australian National Concurrent Design Facility (ANCDF), Australia's first space mission design facility. The ANCDF, at UNSW Canberra Space at the Australian Defence Force Academy, provides the capability to develop space missions from start to finish. It is a tool to accelerate and improve mission concept definition by having a team of collocated experts collaborate concurrently.

The ANCDF was developed based on first-hand experience in similar

facilities in the European space industry. It puts emphasis on customer integration, making implementation cost and scheduling an integral part of the technical design.

Other facilities include:

- Cubesat flatsat infrastructure
- Class 10 000 cleanroom for spacecraft assembly and integration
- Thermal vacuum chamber laboratory with two chambers and solar simulation capability
- Access to Spacecraft test facilities at ANU Advanced Instrumentation Technology Facility
- Space-based instrumentation laboratory
- Electronics workshop
- Satellite ground station (UHF/VHF/S-band)
- Falcon Telescope – the Canberra node of the US Air Force Academy (USAFA) global Falcon Telescope Network, for optical space surveillance and tracking

- A 0.4m, f8 optical telescope forming a Research and Development platform for novel adaptive and electro-optics systems and devices, currently providing on-sky operational adaptive optics imagery
- Impact facilities, including two-stage light gas gun laboratory, suitable for satellite / debris impact studies
- Space debris harpoon development test rig
- Various Unmanned Aerial Vehicle (UAV) platforms and instrumented UAV flight laboratory, for testing GNC approaches
- 64-core workstation for simulation developments; ongoing access to National Computational Infrastructure (NCI) National Facility supercomputer
- Algorithms for multidisciplinary design optimisation and surrogate modelling
- Codes for astrodynamics simulations (coupled Direct Simulation Mote Carlo Particle in Cell or DSMC/PIC, under development) and physics-based space atmospheric modelling
- Three Global Navigation Satellite System (GNSS) satellite simulators and large numbers of GNSS receivers, replayers and software adios
- Thermal vacuum chamber, Helmholtz coils, clean bench, and air bearing bench.

Collaborations

UNSW has a long and strong track record of collaborating with Defence, other Government agencies and industry to build Australia's Defence and civil space sectors. Recent significant collaborations include:

The Woomera Manual project which is an international collaborative research project spearheaded by UNSW's Australian Centre for the Study of Armed Conflict and Society, the University of Adelaide, the University of Exeter and the University of Nebraska. The Woomera Manual on the International Law of Military Space Operations, due for completion in 2020, will become the definitive document on military and security law as it applies to space[1].

1 https://law.adelaide.edu.au/woomera/home

UNSW's Professor Russell Boyce is the program lead in the Intelligent Space Systems Cooperative Research Centre for Smart Satellite Technologies and Analytics (or 'SmartSat CRC'), which is the largest ever Australian investment in space industry research and development.

It involves a $190 million cash and in-kind investment from 84 research and industry partners. The SmartSat CRC will create leapfrogging technologies in advanced telecommunications and smart satellite systems to build Australia's space infrastructure for advanced communications and connectivity, remote sensing, and monitoring for its land, seas and oceans. Professor Boyce will lead collaborative research activities focused on developing agile, maneuverable and resilient satellites; adaptable payloads; and space artificial intelligence applications.

The Buccaneer Risk Mitigation Mission cube satellite, developed jointly by the university and the Defence Science and Technology Group, was launched from Vandenberg Air Force Base in California in November 2017. The satellite remains in orbit performing calibration research for the Jindalee Over-the-Horizon Operational Radar Network. The international Falcon space surveillance telescope network, including the UNSW node, has been used to collect considerable amounts of data on Buccaneer's attitude in Low Earth Orbit, supporting space situational awareness research.

It involves a $190 million cash and in-kind investment from 84 research and industry partners.

UNSW is collaborating with the Royal Australian Air Force to conceptualise, design, build, deploy and control multiple cubesats to develop Australia's future Defence space capability, conduct maritime surveillance, and deliver research and educational outcomes for Defence and civilian students studying engineering at UNSW. The spacecraft are able to gather remote sensing information

with radios and cameras, and have re-programmable software defined radios (SDR) on board, allowing multiple uses during their life.

Other UNSW research collaborations include:

- Off-Earth mining investigations with NASA, the European Space Agency's Moon Village program, iSpace, the Luxembourg government and United Launch Alliance
- GNSS Reflectometry with Airbus, the University of Western Australia and Lloyd's Register
- Garada project (SAR satellite phase 0) with BAE Systems, Astrium (now Airbus Defence and Space) and General Dynamics
- Founding of Delta V with the University of Sydney and Saber Astronautics
- ARC Training Centre for Cubesats, UAVs and their Applications with Defence Science and Technology Group, the Bureau of Meteorology and Saber Astronautics
- GNSS Interference with GPSat Systems.

Key personnel

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Miniature satellite-based science and technology, integrating technologies including quantum communications, on-board processing, reconfigurable payloads, and laser-based and hyperspectral sensors with space engineering

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Satellite navigation systems, satellite systems, space policy, satellite communications, remote sensing, signal processing

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Laws of the sea, maritime law enforcement, laws of armed conflict, national security law, space law

Professor Serkan Saydam – Australian Centre for Space Engineering Research

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Ground control in mining, mining systems, mine planning and design, advanced mining technologies and off-Earth mining

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Mobile and wireless communications, information theory and error control coding, turbo coding and iterative processing, space-time coding, processing and MIMO techniques, wideband CDMA and OFDM, satellite communications

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Signal processing; navigation and position fixing; satellite, space vehicle and missile design; engineering/technology instrumentation; wireless communications; analytical spectrometry; satellite communications

Dr Melrose Brown, Lecturer and Space Program Coordinator, UNSW Space

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Space situational awareness research, Direct Simulation Monte Carlo (DSMC) and Particle-in-Cell (PIC) simulations of space vehicles in Low Earth Orbit (LEO), orbit propagation and determination techniques, high fidelity drag modelling of LEO satellites, physics-based atmosphere modelling and approximation, hypersonic computational fluid dynamics

Dr Joon Wayn Cheong – UNSW School of Electrical Engineering and Telecommunications

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Electrical and electronic engineering, satellite communications, signal processing, photogrammetry and remote sensing, navigation and position fixing, spacecraft development, GNSS integration and interference

Dr Nikki Coleman – Adjunct Lecturer, UNSW Canberra Space

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Space ethics, space terrorism, military space ethics, space bioethics especially consent for medical experimentation and genomic data use in bioweapons

Dr Eamonn Glennon – Senior Research Associate at the Australian Centre for Space Engineering Research

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Navigation and position fixing, signal processing, geomatic engineering, specialised GNSS receiver design

Dr Doug Griffin – Spacecraft Project Lead, UNSW Canberra Space

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Engineering management of high technology programs in the areas of space science and spacecraft engineering

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Skills and capability

The University of Queensland (UQ) is at the forefront of space research in Queensland with teams working on hypersonic flight, earth observation and remote sensing and the development of advanced materials for processing and manufacturing. UQ's three long-established centres in these areas form the foundation of the university's space capability, which includes many existing affiliations and connections with the rapidly expanding global space industry.

In addition to these concentrations of research expertise of direct relevance to space industries, our expertise in mining and minerals processing often involves working in harsh and remote environments while robotics and other aspects of automation that involve close industry collaborations with Australian SMEs and large international firms provide us with skills and capabilities that readily transfer into working in space and extraterrestrial environments.

Start-up company Hypersonix is poised to take UQ's space launch capabilities into the market. In addition to undertaking leading edge research

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

and collaboration with industry, UQ is also making its own foray into the developing space industry sector.

Research strengths

Hypersonics

Sustainable Space Launch

UQ has developed the SPARTAN small satellite launch system, which is a scramjet-based space launch system that is 80 per cent re-usable.

Hypersonic Facility Development

UQ pioneered the development of free-piston based hypersonic facilities and continues to perform to expand their performance.

UQ Composites Group

High temperature composites also known as Ceramic Matrix Composites (CMCs) are mainly composed of a ceramic matrix and carbon or silicon carbide fibres. Unlike alloys, CMCs

UQ has developed the SPARTAN small satellite launch system, which is a scramjet-based space launch system that is 80 per cent re-usable.

It has the potential to revolutionise the space launch industry by bringing aircraft-like operations to space. More than 30 years of ongoing scramjet research underpins this technology.

Thermal Protection during Planetary Entry

UQ makes use of its X2 and X3 facilities to help NASA and ESA determine accurate heat loads for their space missions. This involves developing new measurement techniques and instrumentation.

are lighter and can handle high mechanical stresses — even as high as 2000–3000°C.

Such characteristics bring CMCs to the edge of the material science. These advanced materials are used for ceramic brake disks on super cars, turbine blades for jet engines and fins on hypersonic vehicles.

To manufacture circular shapes such as rocket bodies or nose cones, UQ Composites uses a filament winder capable of winding bodies up to 1.5 m

long. The winder is equipped with four axis, allowing the winder to work on complex shapes. Because of the high temperatures involved during the manufacturing processes, one of the big challenges is the production of complex shapes.

UQ Composites recently manufactured a curved CMC piece for a rocket, with an embedded thermocouple. Because Ceramic Matrix Composite materials are challenging to test and validate, UQ Composites is to have its own oxyacetylene torch test set up. This a simple and cost-effective way to test high-temperature materials as the torch tip can heat up to 3000°C.

Quantum Technologies

UQ has substantial capacity in quantum technologies for space applications. The University is developing disruptive aerospace sensors based on techniques developed for quantum science. This includes magnetic field sensors and communication devices for space science and communications, with performance equal to state-of-the-art cryogenic magnetometers, but operating on a silicon chip in ambient conditions. This greatly reduces the size, weight, and power, crucial for many space applications. The university is developing new computer processors for the aerospace industry, based on the flow of phonons (quanta of mechanical vibrations) rather than electrons. These architectures are intrinsically robust to the ionising radiation present in space.

The ability to operate communication and computing systems in radiation-harsh environments would have real impact and major societal benefit. Radiation from solar flares and space weather disrupts global positioning. It is estimated that a 100-year solar flare event would cause more than US$1 trillion in damage, leaving millions of people without power or communications for months or years[1].

The University is an international leader in the foundations of quantum cryptography, which has recently been deployed by China to provide secure ground-to-satellite communications.

1 National Academies of Sciences 2014, Severe Space Weather Events – Understanding Societal and Economic Impacts: A workshop Report (2008)

UQ researchers are working directly with industry and international university partners to provide an Australian capability in quantum cryptography for space.

UQ Earth Observation

The Remote Sensing Research Centre (RSRC)[2] at UQ is recognised as an Australian and global leader in developing science and applications that deliver information from satellite imaging systems (earth observation) to support a broad range of industry, government and defense applications. The RSRC is the largest and longest running earth observation research and training centre in Australia. A central component of its success is the Joint Remote Sensing Research Program (JRSRP)[3]. The JRSRP was developed in collaboration with the Queensland Government and delivers research solutions to Australian state and territory agencies for using earth observation as part of their legislated mapping, monitoring and management programs.

Most recently UQ has become leads of Earth Observation Analytics, which is one of three research programs in the newly approved CRC Round 20 proposal bid – the SmartSAT CRC[4] with $46 million in industry funding.

UQ also operates Earth Observation Australia[5] representing industry, all levels of government, research institutions and academia, collecting and analysing data from earth observing satellites to deliver commercial and government services in Australia. This was developed at UQ, and operates under a 10-year plan to 2026.

UQ Centre for Advanced Materials Processing and Manufacturing (AMPAM)

Machining research at AMPAM investigates new technologies that can be used to machine aircraft components more efficiently.

AMPAM projects with companies such as BAE Systems Australia through the Defence Materials Technology Centre have been successful in developing techniques to machine titanium components for the F-35 Joint Strike Fighter, a $300 billion program expected to produce 6000 aircraft.

2 www.rsrc.org.au

3 www.jrsrp.org.au

4 www.smartsatcrc.com

5 www.eoa.org.au

A scramjet rocket launching into a light blue sky – courtesy of The University of Queensland

UQ has developed the SPARTAN small satellite launch system, which is a scramjet-based space launch system that is 80 per cent re-usable.

Research infrastructure

UQ's Centre for Hypersonics has three world class hypersonic wind tunnels. All are free-piston based facilities, with experimental test times measured in milliseconds. These are the only facilities that can generate true hypersonic flight conditions at speeds above Mach 7. UQ pioneered the development of free-piston type facilities, which have now been copied by numerous groups around the globe. The facilities are:

- T4 shock tunnel – world's most productive facility for scramjet testing with over 12,000 experiments since 1990.
- X2 expansion tunnel – facility for fundamental research on earth re-entry and the entry into the atmospheres of other planets.
- X3 expansion tunnel – larger version of X2 that can accommodate bigger models and generate flows for longer periods.

The UQ Composites Group furnace allows high-temperature processing and development of CMCs. It is a

GCF 1700 type high-temperature furnace from Across International that can reach 1700°C (depending on the atmosphere). This 40 cm x 30 cm x 30 cm furnace chamber has a maximum heating rate of 15°C per minute. UQ Composites will soon acquire an ultra-high temperature furnace that can reach temperatures up to 2700°C. This furnace will assist better understanding of the carbon graphitisation process.

UQ has state-of-the-art micro- and nanofabrication facilities, provided through the Australian National Fabrication Facility (Queensland Node) and the Centre for Microscopy and Microanalysis, and state-of-the-art photonic and electronic integration, packaging and prototyping facilities provided through the UQ Precision Sensing Initiative and Australian Centre for Engineered Quantum Systems. These facilities allow the design and fabrication of precision quantum and photonic technologies at the few-nanometre level, and their deployment into applications.

UQ Earth Observation

UQ has research infrastructure for the calibration and validation of measurements and maps from earth observation sensors on satellite, aircraft and drones. These are nationally and internationally unique, and include instrumentation for use in terrestrial and marine environments: spectrometers, photometers, survey grade terrestrial laser scanners, drones and drone sensors, and high precision position measurement devices. These instruments have been sourced through participation in key National Collaborative Research Infrastructure Strategy (NCRIS) initiatives.

UQ's Centre for Hypersonics has three world class hypersonic wind tunnels. All are free-piston based facilities, with experimental test times measured in milliseconds.

Collaborations

In the area of hypersonics, UQ has collaboartions with NASA for heat shield design for probes to Mars, ESA for heat shield designs, Defence Science and Technology for Scramjets and Hypersonix Pty Ltd for the Sustainable Space Launch

The university collaborates with Lockheed Martin and NASA Glenn Research Centre on the development of quantum technologies for aerospace applications.

The Allen Global Coral Atlas[6] project is a collaboration with Paul G. Allen Philanthropies for support on funding, development, communication and management; Planet for global imagery and processing; the Carnegie Institution / Arizona State University for water column correction and monitoring protocol; the National Geographic Society lead global engagement and verification activities; and the Remote Sensing Research Centre for the actual mapping. Geomorphic and bottom composition maps are and will be available through the Allen Coral Atlas.

Key personnel

Hypersonics

Professor Richard Morgan

Re-entry and Planetary entry

Professor Michael Smart

Sustainable space launch

Professor David Mee

Hypersonic aerodynamics

Professor Allan Paull

Electric Propulsion

Associate Professor Vincent Wheatley

Hypersonic simulation

Quantum Technologies

Professor Warwick Bowen

Quantum and photonic technologies for aerospace applications

Professor Timothy Ralph

Quantum communication in space and earth-orbit

Associate Professor Tim McIntyre

Optical analysis of turbulence in hypersonic flight

6 allencoralatlas.org

UQ Earth Observation

Professor Stuart Phinn

Global Lead Earth observation applications and coordination in terrestrial and Marine

Dr Peter Scarth

Global large area and long time series earth observation analytics

Dr Chris Roelfsema

Global earth observation for coral reefs and coasts

Mr Neil Flood

Australia/Global earth observation

Dr Adrian Fisher

Australia- earth observation, large area biophysical data processing

Dr Anthea Mitchell

Australia earth observation for imaging radar

Dr James Watson

Australia earth observation for large data analytics

Dr Leo Hardtke

Australia earth observation for fire and large data analytics

Dr Jordan Graesser

Global earth observation for time series image analysis and agriculture

Dr Zunyi Xie

Global earth observation biophysical applications

Dr Lucia Morales Barquero

Australia earth observation image mapping

Dr Rodney Borrego-Acevedo

Australia earth observation for large area and high spatial resolution

Dr Eva Kovacs

Australia earth observation for coastal environments

Dr Emma Kennedy

Global coral reef ecology

Ms Kate Markey

Australia coral reef ecology

Dr Meredith Roe

Australia- earth observation for large area and high spatial resolution

Dr Mitchell Lyons

Australia earth observation for terrestrial and marine ecology

Dr Nick Murray

Global applied ecology and spatial analytics

UQ Composites Group

Associate Professor Martin Veidt

Applied mechanics covering all aspects of through life support of materials and structures with a special focus on composites such as fibre-reinforced laminates, sandwich structures and hybrid metal fibre laminates

Dr Michael Heitzmann

Advanced composite materials and processes and new product development

The University of Sydney

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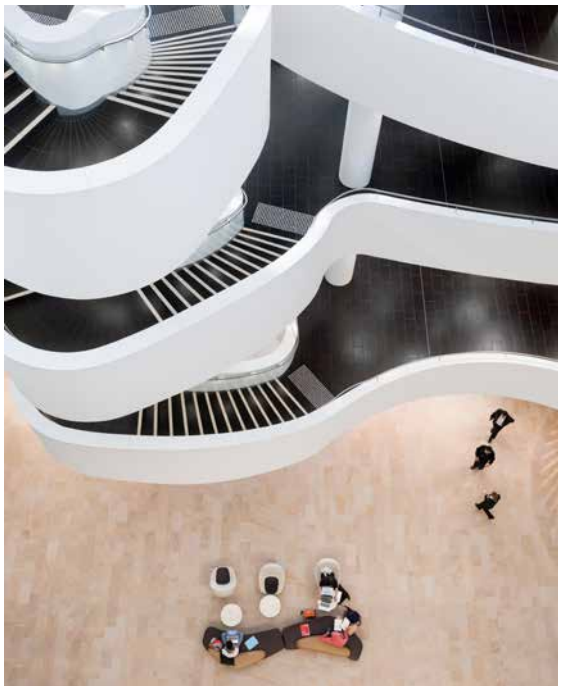

Skills and capability

As one of the global leaders in robotics and intelligent systems, the University of Sydney is tackling fundamental challenges in space science and technology from advanced composite structures, hybrid propulsion systems, unmanned aerial vehicles and control algorithms to complete satellite systems.

The University combines unique multidisciplinary capabilities to undertake emerging space research and develop technologies to address current and future challenges in security, defence, commercial aviation, agriculture, environmental monitoring and space exploration.

Committed to the development of space research and technologies, the University of Sydney is partnering both nationally and internationally with world-class government agencies, research institutes and industry experts to investigate new areas of space.

The Australian Centre for Field Robotics is one of the largest robotics research institutes in the world

THE UNIVERSITY OF SYDNEY

Research Strengths

Aerostructures and Advanced Materials

The School of Aerospace, Mechanical and Mechatronic Engineering is one of Australia's premier engineering schools and specialises in the design, analysis and operation of flight and space vehicle systems.

The Centre for Advanced Materials Technology conducts high-quality fundamental research in materials science and technology and promotes collaboration with industry in the design, engineering, development and manufacturing technology of advanced materials.

Artificial Intelligence

In partnership with a world-leading robotics company, the UBTECH Sydney Artificial Intelligence Centre brings together a multidisciplinary team of dedicated researchers to explore artificial intelligence and potential applications in the space sector.

Autonomous Systems

The Australian Centre for Field Robotics is one of the largest robotics research institutes in the world and focuses on the development and application of autonomous robotic and intelligent systems. The Centre is developing an experimental planetary rover with increased mobility compared to the conventional Mars Curiosity Rover.

Communication

The Centre for IoT and Telecommunications is pioneering advanced, industry-supported wireless communications and networking research, focusing on emerging research fields such as 5G mobile, IoT, signal processing for communication, advanced coding and quantum imaging.

Earth Observations

Spacenet plays an integral role in international space efforts and uses earth observations and weather data collected from space for land-sea-air evolution, resources, food security and triple-bottom-line analyses. This data is vital for the monitoring, detection, prediction and classification of features and phenomena in coasts and oceans, the atmosphere, agriculture, vegetation, and ecosystems.

The University of Sydney

Propulsion and Flight Dynamics

The Propulsion Lab focuses on hybrid fuel-cell-based propulsion systems, small variable pitch propellers and micro gas turbine systems. Each of these technologies are designed to solve the industry bottleneck that is small-to-medium sized unmanned aerial vehicles.

Space Systems

The University has internationally-recognised expertise in the design and development of innovative unmanned aerial vehicles which has been applied to multiple research projects involving airframe systems, instrumentation, flight simulation, flight dynamics, control, guidance and navigation, flight testing, system characterisation, flight operations and market analysis. The University's Small Satellites Program includes the design of small satellite systems and high-altitude atmospheric test platforms for satellite sensor development and technology verification. Micro-satellites and small-satellites with a mass range from 1kg to 200kg, with the capability to accommodate both scientific and commercial payloads are under development.

Research infrastructure

The University of Sydney's research infrastructure includes a number of high-end facilities to support research into space related activities.

- In Aerostructures and Advanced Materials, the Microscopy and Materials Characterisation Laboratory is equipped with a wide range of equipment from Rigaku MSF-3M X-ray stress analyser to Struers automatic polishing system, for studying a variety of material properties including determining sample structure, composition, thermal and mechanical properties.
- The purpose-built Sydney Nanoscience Hub also hosts three of the University of Sydney's core research facilities that support leading research in materials characterisation nanotechnology, advanced manufacturing, solid mechanics and biotechnology.
  - » The Research and Prototype Foundry offers instruments for the fabrication of devices and structures with features on the micro and nanoscale, with specialised processes allowing users to make devices and prototype new ideas.
  - » Sydney Analytical provides state-of-the-art instruments and technical expertise for sample characterisation.
  - » Sydney Microscopy and Microanalysis has a wide range of microscopy instrumentation, including atom probe tomography, to explore physical structures at the micro, nano and atomic scales.
- In artificial intelligence the Sydney Informatics Hub provides world-class computational and storage infrastructure, software tools and data analytics and visualisation services to enable a broad range of approaches to informatics applicable to space related activities.

The University has internationally-recognised expertise in the design and development of innovative unmanned aerial vehicles which has been applied to multiple research projects ...

The University of Sydney

- The Australian Centre for Field Robotics has major facilities for development of autonomous systems including air, ground and subsea robots. The Field Robotics Laboratory includes a well-equipped electronics fabrication and assembly area, near-field and far-field anechoic test facility, environmental test chamber, individual robot assembly and testing bays, a flight-vehicle fabrication laboratory and a mechanical workshop.
- The Unmanned Aerial Vehicle Laboratory is equipped with rapid-prototyping tools and facilities to develop novel flight systems and support flight operations.
- The University has a Civil Aviation Safety Authority approved flight-testing facility with 20,000 acres of available airspace up to 2000ft AGL as well as a number of wind tunnels fitted out with state-of-the-art instrumentation and data recording systems for the measurement of air-loads, pressures and flow fields.

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- The Clean Combustion Laboratory supports an extensive range of laser diagnostics methods for the measurements of velocity, mixing, temperature and reactive scalar fields in reacting and non-reacting flows for the Propulsion and Flight Dynamics area.

Collaborations

The University of Sydney has a long tradition of innovation and engagement with industry, government and community partners. Examples of our existing research and education based partnerships

across a range of space related activities include:

ARC Training Centre for CubeSats, Unmanned Aerial Vehicles, and their Applications

Led by the University of Sydney, the ARC Training Centre for CubeSats, Unmanned Aerial Vehicles, and their Applications is working to train and create an Australian workforce specialised in sustainable, advanced manufacturing, space and UAV industries. As part of the Centre, a new partnership with Space BD is set to provide satellite deployment services from the International Space Station for two CUAVA satellites that are under development.

The University of Sydney

Cooperative Research Centre for Smart Satellite Technologies and Analytics

The University of Sydney is a key player in one of the most significant space industry research concentrations in Australia as part of a new Cooperative Research Centre for Smart Satellite Technologies and Analytics. The University brings together a multidisciplinary team whose combined expertise spans 5G communications, IoT technology, embedded systems, small satellites and artificial intelligence.

Cooperative Research Centre Project for Responsive Access to Space

As part of a global industry research project, combustion experts from the University of Sydney's are one step closer to developing a more efficient satellite launch platform to drive Australia's space economy. Led by DefendTex, the project includes researchers from the University of Sydney, Universität der Bundeswehr München, the University of South Australia, RMIT, Defence Science and Technology Group and Innosync Pty.

German Aerospace Center

The University of Sydney has partnered with the German Aerospace Center (Deutsches Zentrum für Luft-und Raumfahrt) to investigate the design and development, building and testing, as well as integration and launch of new satellite technologies.

Key personnel

Aerostructures and Advanced Materials

Professor Julie Cairney

Professor Lin Ye

Professor Liyong Tong

Artificial Intelligence

Professor Dacheng Tao

Associate Professor Fabio Ramos

Dr Tongliang Liu

Autonomous Systems

Professor Eduardo Nebot

Professor Salah Sukkarieh

Associate Professor Ian Manchester

Communications

Professor Branka Vucetic

Professor Yonghui Li

Dr Zihuai Lin

Earth Observations

Professor Dietmar Muller

Dr Eleanor Bruce

Dr Bradley Evans

Propulsion and Flight Dynamics

Associate Professor Matthew Cleary

Associate Professor Ben Thornber

Dr Dries Verstraete

Space Systems

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The University of Western Australia

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Skills and capability

The University of Western Australia (UWA) delivers broad research and technology solutions for the challenges facing the nation's space industry today and for the future.

Western Australia's remote geographic location, dry environmental conditions and high air quality has been an attractive setting for major space projects since the 1960s. These unique qualities minimise electromagnetic interference and the longitude in the Southern Hemisphere means that the night sky can be monitored at all times.

Research strengths

UWA engages in a broad spectrum of research including astronomy and supercomputing, advanced sensing, quantum technologies, space governance and exploration and comprehensive health research. Research areas include:

- Astronomers, engineers and data specialists from the International Centre for Radio Astronomy

Research (ICRAR) contributing to the end-to-end design, construction, data processing and science extraction for the Square Kilometre Array (SKA).

- Specialisation in antenna design, radio-frequency engineering, electromagnetic compatibility, high-performance computing, digital systems and software engineering.
- Current engineering research includes SKA Signal and Data Transport (SaDT) phase and frequency synchronisation studies.
- UWA's astronomers are regular uses of space telescopes with guaranteed time observations on many upcoming NASA, European Space Agency (ESA) and other space agency missions studying gravity, dark matter and energy production. In particular, UWA specialises in the federation of data acquired across the full wavelength range (x-ray to radio), by combining space-telescope data with ground-based radio and other datasets through innovative software and big data management.
- Developed coherent detection of digital communication using broad-band phased stabilisation system.
- In support of next-generation computational technologies, the Frequency and Quantum Metrology Research Group are world leaders in precision measurement involving frequency, time and quantum systems. Research includes miniaturised gravity gradiometer, interferometric EM gradiometer, microwave sensors and precision

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oscillators and clocks. The group uses advanced mathematical methods and numerical techniques to model the dynamics of quantum systems and investigate quantum algorithms.

- UWA's QUISA research group (Quantum Information, Simulation and Algorithm) combines expertise in quantum physics, pure and applied mathematics, data processing, machine learning, computing temporal logic and algorithm, which provides the promise of solving certain problems of practical significance otherwise intractable. The QUISA group explores applications in quantum simulation, data processing, financial risk analysis, machine learning and classification, taking advantage of intrinsic quantum correlations and quantum parallelism. In particular, they examine which parts of existing classical algorithms can be sped up in the quantum setting with deterministic queries.

- Next generation technologies in remote operations, new materials for sensor fabrication, novel sensor architectures to sensor readouts and data analysis. Development of new class infrared detection, imaging and multi- and hyperspectral sensors, terahertz band sensing, optical fibre systems, high sensitive magnetometers single-chip gas, chemical, pressure and temperature sensors.
- Computer vision for ground, underwater or ground platforms with focus on target detection, recognition, classification, tracking and subtle change detection, particularly tools for machine learning in 3D biometric, RGB-D object segmentation and recognition, robot grasping and sub-sea ecology projects.
- Data science, machine learning and artificial intelligence including new algorithms, artificial neural networks and computational intelligence for optimisation, modelling and control.
- Designing and building hardware, electronics and software for almost 100 driving, walking, swimming/diving and flying robots.
- Signal and image processing, separation of acoustic signals using remote sensors, audio-visual data, and human speech recognition systems – for human machine interface.
- Intelligent systems, artificial neural networks, biomedical engineering, control, digital signal processing, parallel and distributed computing, image processing, pattern recognition and software engineering.
- The ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav)-UWA centre is based

The ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav)-UWA centre is based in the School of Physics and is part of the Australian Consortium for Interferometric Gravitational Astronomy (ACIGA).

in the School of Physics and is part of the Australian Consortium for Interferometric Gravitational Astronomy (ACIGA). Main areas include: technology for gravitational wave detection, gravitational wave data analysis, multi-messenger astronomy and astrophysics, spin-off technologies and teaching and learning of Einsteinian Physics.

supervised students in the broader area of international space and aviation law.

- Our researchers are published widely on a range of social, political, philosophical and environmental issues underpinning space exploration, including space debris in the orbital commons, the robotic exploration of Mars, space as a

UWA researchers include private, public international and comparative lawyers with particular research interests at the interface between science, technology and law.

- UWA researchers include private, public international and comparative lawyers with particular research interests at the interface between science, technology and law. Topics include the governance of satellites, drones and remote sensing technologies, and the use of data gathered from satellites, drones and autonomous vehicles for surveillance, monitoring and law enforcement. Our researchers have also published, taught and

global commons, space tourism and extra-planetary mobilities.

- Work design, resilience and performance related to the cognitive mechanisms that underlie human performance in safety-critical work contexts.
- Prospective memory, situational awareness, human interaction with automated systems and error from interruptions, distraction and multitasking.

- Chemical measurement of stress, assessment tools for screening and early detection of mental health problems, remote health provision using wearables.

Research infrastructure

- Australian National Fabrication Facility (ANFF) node at UWA is a state-of-the-art facility in infrared technology and micro electro mechanical systems fabrication processes for industry and broader research communities.
- The Microelectronics Research Group runs a completely vertically-integrated sensor facility, from materials growth, through device design, fabrication and testing, to packaging and sub-system assembly.
- Centre for Microscopy, Characterisation and Analysis provides world-class microscopy and microanalysis facilities.
- Pawsey Supercomputing Centre, which operates multiple supercomputers, data-intensive machines and storage systems.
- ESA operates one of the world's largest radio dishes as a Deep Space Tracking station and routinely downlinks data from their space missions.
- Western Australian Space Centre (WASC) hosts NASA's satellite laser ranging facility, one of only two stations in the Southern Hemisphere.
- UWA has developed the necessary expertise and specialised equipment to operate a dedicated Astronomy and Space Instrumentation Lab.
- UWA operates Gingin observatory which hosts rapid response, launch tracking and space debris tracking facilities and the Zadko telescope.
- OzGrav's UWA node operates the Australian High Optical Power Gravitational Wave Research Facility at Gingin in Western Australia. The facility was built in collaboration between Australian Consortium for Gravitational Wave Astronomy (ACIGA) and the LIGO consortium, and is used primarily for developing gravitational wave instrumentation.

Collaborations

UWA's internationally recognised research leaders are tackling global, national and regional issues to improve the lives of others and ensure that knowledge and evidence is translated into benefits for society.

As an innovation leader UWA understands the role that research institutes play in the economy of building and sustaining the economy and ensuring there is a pipeline that is required to ensure the very important job creation and economic diversification.

Key research collaborations include the International Centre for Radio Astronomy Research (ICRAR) which was founded in August 2009, jointly by UWA and Curtin University, with the specific purpose of supporting Australia's bid to host the SKA. ICRAR is well positioned to broaden its focus to include space communications, small satellite development, space tracking and transient monitoring astronomy. In 2014, Deloitte Access Economics identified ICRAR as being one of the top five centres of its kind in the world.

UWA also has a research collaboration agreement with the Japanese National Institute of Information and Communications Technology (NICT) related to satellite-to-ground laser communications. NICT has numerous satellites to collect spectral data for economic purpose, disaster prevention and rescue, and data communications. NICT recently launched an experimental satellite to demonstrate the use of laser transmission to increase the band-width.

As part of the inaugural Defence Science Technology (DST) Counter Improvised Threats Grand Challenge initiative UWA was successful in collaboration to develop high-tech sensors that could detect bombs in public places.

At the same time UWA is actively engaged with NASA and ESA and other agencies such as Airbus and Goonhilly capitalising on WA's location and transparent skies by hosting a range of facilities associated with space situational awareness, launch tracking, and space-communications from various locations including Gingin Observatory and the Western Australian Space Centre.

THE UNIVERSITY OF WESTERN AUSTRALIA

Key personnel

Professor Mike Tobar – Professor

Faculty of Engineering & Mathematical Science, School of Physics, Mathematics & Computing

Professor Erika Techera – Professor of Law

Faculty of Arts, Business, Law and Education

Professor Lorenzo Faraone – Head, Microelectronics Research Group

Faculty of Engineering and Mathematical Sciences, University of Western Australia

Professor Brett Nener

Microelectronics Research Group, Faculty of Engineering and Mathematical Sciences

Professor Peter Quin – Director

International Centre for Radio Astronomy Research (ICRAR)

Professor Simon Driver

International Centre for Radio Astronomy Research (ICRAR)

Professor Mark Reynolds – Head of School

Faculty of Engineering & Mathematical Science – School of Physics, Mathematics & Computing

Professor Dilusha Silva

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Professor Adrian Keating

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Associate Professor Shayne Loft – Deputy Head of School of Psychological Science

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Professor Gia Parish – Associate Dean of Research

Faculty of Engineering and Mathematical Science

Professor Jingbo Wang – Head of School of Physics

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GROUP OF EIGHT AUSTRALIA

MEMBERS

THE UNIVERSITY OF WESTERN AUSTRALIA

MONASH University

Australian National University

THE UNIVERSITY of ADELAIDE

THE UNIVERSITY OF MELBOURNE

UNSW

THE UNIVERSITY OF QUEENSLAND AUSTRALIA

THE UNIVERSITY OF SYDNEY

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