



Space Environment Research Centre

Annual Report
2015 - 2016



Australian Government
Department of Industry,
Innovation and Science

Business
Cooperative Research
Centres Programme

This report has been prepared in accordance with the 2015/16 Cooperative Research Centre's Programme Annual Report Guidelines and is submitted to comply with the requirements of Section 4 of the Guide.

The Cooperative Research Centre for Space Environment Management is administered by the Space Environment Research Centre Limited (SERC).

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REPORT

from the Chair

I am pleased to report that the Cooperative Research Centre (CRC) for Space Environment Management, under the administration of the Space Environment Research Centre Limited (SERC), has continued to achieve success through its second year. SERC has made significant progress in the research arena and is tracking well to pre-set milestones.

We are particularly pleased with, and proud of, our cadre of up-and-coming space professionals. We have scholarship students at universities in Victoria, South Australia, Queensland, New South Wales and the Australian Capital Territory. These bright and capable young people are working hard to master the complexities of the field and to establish themselves as the future space researchers of Australia and beyond.

I would like to thank all SERC Participants for their support in achieving this progress with the research objectives for the CRC. SERC is building a reputation internationally as a successful and productive research collaboration which is a credit to everyone involved. Our early momentum puts us in a strong position to consolidate on the early advances we have made through new strategic collaborations which can further reduce risk and later accelerate the uptake of SERC technology.

I would also like to extend my gratitude to our CEO, Dr Ben Greene, and his management team, all the researchers in the CRC, and my fellow Board members for continuing to ensure SERC operates efficiently and achieves the objectives of our organisation.

In the upcoming year we look forward to welcoming some new international partners who will contribute skills, experience and resources towards addressing the significant task ahead of us: the preservation of space for our future.



Mary O'Kane

Chair

REPORT

from the CEO

In its second year the CRC has settled into an operational tempo which has it tracking well towards its key objectives in research and education.

We have actively managed SERC funds and recruited high-calibre staff from within Australia and internationally to ensure that our total research resources are consistent with the objectives we have set.


Students are the next layer of space capability and we now have a strong and diverse group of capable nascent researchers associated with our research programs.

SERC has been well represented by staff and students alike, at national and international events in the space arena. Papers, posters and publications have been prepared and presented for the scrutiny of leading space professionals in significant international fora. This is a key part of a continuing process of applying elite peer review to refining the direction of our research programs, and assessing the utility of continuing each effort.

An example of the refinement of our research direction is our creation in 2015/16 of a new research program which will focus on building and launching satellites for the systematic evaluation of all current SERC research programs. This new program will improve outcomes from all our current programs as we will be better able to verify in space our innovations in tracking, orbit determination, prediction and the manoeuvre of space objects.

Another important new development going forward will be the inclusion of Participants from other international space organisations. SERC research efforts are now established with strong forward momentum, and new resources can be added with little risk of assimilation issues consuming the expected benefits of adding resources. We will carefully screen potential new Participants to ensure we add resources and capabilities which complement those already in the CRC.

In the past twelve months we have moved closer to our aim of minimising and eventually eliminating the threat to space infrastructure from space debris.



Ben Greene

Chief Executive Officer



SERC 1.0 EXECUTIVE SUMMARY

1.0 EXECUTIVE SUMMARY

The Cooperative Research Centre (CRC) for Space Environment Management is operated by the Space Environment Research Centre (SERC), an Australian Public Company, Limited by Guarantee. The CRC is funded through the Department of Industry, Innovation and Science's CRC Programme and through Participant contributions.

SERC's purpose is to pursue and promote world class research and education in the measurement, monitoring, analysis and management of space debris, and to develop technologies to preserve the space environment.

SERC brings new resources to this purpose, but it also consolidates otherwise-independent research efforts towards achieving a critical mass of effort to address an immense global problem. SERC aims to attract collaborators by providing:

- A transparent and proven statutory and organisational framework for international research collaboration, ensuring equity for all collaborators regardless of nationality and whether a private or public entity;
- Access to state-of-the-art SERC space research programs and infrastructure;
- New funds for consolidating research program synergies and investigating new avenues; and
- Exemplary management of research; consistent focus and strategic leadership.

1.1 ACHIEVEMENTS

During the second year of operation, SERC has consolidated the achievements of the first year:

- **Research.** SERC Research Programs (RPs) made satisfactory progress during this period, but more importantly developed significantly more momentum towards SERC objectives.
- **Financial management and discipline.** SERC continues to prioritise funds for research purposes, keeping a very tight rein on all expenditure not directly supporting our research, as well as maintaining the highest level of accountability in research investments.
- **Recognition as a registered charity.** From inception SERC has been exempt from income tax and stamp duty; and enjoyed GST (Goods and Services Tax) concessions and an FBT (Fringe Benefits Tax) rebate. During 2015/16 SERC was recognised as an Approved Research Institute (ARI) and endorsed as a deductible gift recipient, able to receive tax-deductible donations.
- **Corporate Governance.** SERC updated its policies and procedures to conform to its new role as a charity while still remaining compliant with prior statutory requirements. Constitutional change was approved by SERC members to allow SERC to become a charity and an ARI.
- **Research Management.** The Research Management Committee admitted a new independent Committee Member. During 2016/17 SERC will permanently establish a majority of independent members on this Committee.
- **Annual Research Review.** A full research review was completed by the Research Management Committee in June 2016. As a result some research activities have been terminated with resources re-directed to

1.0 EXECUTIVE SUMMARY

1.1 ACHIEVEMENTS

other existing areas. For example research into space weather has been terminated with resources now applied to atmospheric density research. Another result is the merging of two existing RPs (RP1 and RP4) and the creation of a new RP4 which will design, build, test, launch and operate satellites.

- **Scientific Collaboration.** SERC held two successful colloquia this year, providing opportunities for researchers to discuss their respective programs and to identify and maximise collaboration between programs. The November 2015 and May 2016 colloquia included representatives from all Participants, programs and program themes. Researchers and students presented their research to their peers; to RP Leaders; and to the members of the Research Management Committee. Participants and the Committee gained a deeper understanding of the progress of the research across all programs. The colloquia also provided opportunities for questions, feedback and face to face meetings in small focus groups. Feedback from Participants was extremely positive. The Research Management Committee met immediately following the May colloquium and their review was thoroughly informed by the preceding colloquium.
- **Intellectual Property (IP).** At the May 2016 colloquium Justin Coombs, General Manager of the CRC for Cell Therapy Manufacturing and a registered patent attorney, gave a presentation providing a basic overview of IP Identification and Protection. This session was open to all Participants and focussed on the importance of managing IP for the benefit of the CRC and all its Participants.
- **Media.** SERC achieved a substantial media profile in 2014/15. This was consolidated in 2015/16.

SERC's Facebook page, launched in March 2015, has maintained regular posts pertaining to SERC's activities and subject matter related to SERC's RPs. It now has a following of over 500. There was extensive media coverage during the SERC May 2016 Colloquium, with multiple stories and interviews across a variety of media.

- **Scholarships.** In the first half of 2016, SERC awarded two undergraduate scholarships and 13 scholarships supporting a higher degree by research. This growing pool of exceptional students positions us well to achieve both our educational milestones and our strategic objective of growing space capability within Australia.

1.0 EXECUTIVE SUMMARY

1.2 RISKS AND IMPEDIMENTS

During this reporting period SERC has experienced no impediment nor any new risk which would materially degrade its ability to meet its objectives:

Risk Mitigation

During this year the SERC Audit Committee and Risk Management Committee were merged into a single Audit and Risk Management Committee with a focus on identifying and managing risks and impediments to the successful delivery of SERC objectives.

SERC maintains a comprehensive Risk Register which is reviewed regularly by management and the Audit and Risk Management Committee. Risks with a high impact rating and an increase in probability are promptly reported to the Board. The Research Management Committee also reviews and reports to the Board regarding any specific risk increase relating to the research.

Key risks addressed during the reporting period and strategies adopted to address these risks were:

- **Loss of Key Researchers.** This is an ongoing business continuity risk. This is addressed through controls including quarterly project meetings, continuous international search to identify and recruit subject matter experts, and annual stakeholder reviews. This effort is supported by Research Management Committee oversight.
- **Research Outsourcing.** Wherever possible SERC applies industry-standard research contracts to outsource its research requirements. The outsourcing of research allows SERC to run a leaner structure and internally focus on the technology elements of our mission not achievable elsewhere. The research contracts cannot demand results, but they do mandate research process, quality systems,

documentation, resource focus and record-keeping. There has been considerable stress in some contractors as these requirements are enforced by SERC, but real progress has been made towards both compliance and research results.

- **Conflict of Interest.** SERC operates for the collective benefit of its members and the Commonwealth. The potential always exists for a conflict of interest between one (or more) members and the collective. A vigilant Contracts and Licenses Committee monitors all SERC transactions (financial and IP) to ensure the collective interest is upheld, and this committee's efforts are supported by a formidable array of process and procedure.

Through the application of the SERC risk management process and the deliberate application of resources the following risks have been revised downwards from high to moderate impact:

- **Intellectual Property.** The key IP risks relate to inadequate protection or poor exploitation. SERC relies on experienced RP leaders to implement SERC IP processes. The inclusion of robust non-disclosure and IP protection clauses in Participant Agreements and staff and student contracts is a key element. To enhance awareness, an IP workshop was conducted at the May 2016 Colloquium to assist researchers identify and protect SERC IP. Further IP management workshops are scheduled for the next reporting period. During this reporting period background and foreground IP began to be identified and recorded on the SERC IP register. This is an ongoing process.
- **Research Program Failure.** SERC has an efficient but resilient research strategy which can accommodate multiple failures in the necessarily high-risk research

1.0 EXECUTIVE SUMMARY

1.2 RISKS AND IMPEDIMENTS

effort. However there are some research outcomes which are fundamental to the success of our enterprise. These include the use of adaptive optics (AOs) for beam propagation, the response of typical debris to laser radiation, and the achievement of unprecedented power and optical quality in laser beams.

These risks have been managed from “high” to “moderate” during this period through the progress achieved by the research teams. However, the reduction of risk is an ongoing process and any risk can later resurface as initially-attractive solutions are excluded by practical, ethical, schedule or financial considerations.

- **Insufficient Resources.** This risk relates to the quality and quantity of in-kind commitments from Participants. This issue was anticipated in the framing of the SERC constitution where reviews are required annually of both the quantity and quality of in-kind contributions provided to SERC by its Participants for purposes of achieving research objectives. The stipulated processes have been followed, and after two years of application, have achieved a strong degree of acceptance and compliance by all Participants.

1.3 END-USER ENVIRONMENT

SERC’s mission involves developing and commercialising technologies to reduce the threat to space-based infrastructure from space debris. Since the infrastructure is valued at around \$900 billion there would appear to be a ready market for SERC technology, if it can meet user requirements.

End-user engagement is necessary to ensure that SERC research achieves this outcome – and to enhance engagement, four of the six SERC Participants are end-users.

- Optus Satellite Systems (Optus) have a substantial investment in space-based infrastructure and are highly motivated to protect their investment;
- National Institute of Information and Communications Technology (NICT) is a major manufacturer and operator of satellites in Japan and a close collaborator of Japan Aerospace

Exploration Agency (JAXA), the Japanese Space Agency;

- Lockheed Martin (LM) is a major global provider of satellites and of space debris services; and
- EOS Space Systems (EOSSS) owns a satellite in a high-risk zone, and develops commercial technologies to prevent space debris collisions.

These companies represent the potential pool of end-users of SERC IP, either directly or through a service provider, to improve their business performance.

In addition to the internal end-users, external end-users are engaged through the following activities:

- Direct industry liaison and engagement by SERC itself and through Participants;
- Participation at national and international symposia to publicise SERC capabilities; and

1.0 EXECUTIVE SUMMARY

1.3 END-USER ENVIRONMENT

- Colloquia where end-user Participants were engaged and a number of areas were identified where they could inform and further contribute to research activities.

In addition, the Research Management Committee monitors worldwide developments and identifies emerging trends in relation to space technologies

and space debris mitigation. This enables SERC to ensure that its strategic direction aligns with end-user requirements and will deliver economic, environmental and social benefits to Australia as well as to Participants.

1.4 IMPACTS

No substantial changes to the expected impact of SERC as outlined in the Impact Tool (EIPT) have been identified. In holistic terms the overall impact of the CRC will likely have improved due to the effect of increasing space debris combined with a significant increase in asset investment in space.

As SERC research advances it is becoming clear that SERC-developed technology may have different impact at different orbital altitudes, and more research is required before this can be mapped directly to impacts.

A satellite with a gold-colored thermal blanket is in orbit above Earth. The planet's surface is covered in white clouds over a blue ocean. The satellite's structure, including a cylindrical body and various instruments, is visible in the upper right corner.

SERC 2.0 RESEARCH

2.0 RESEARCH

2.1 CHIEF INVESTIGATORS



Prof. Craig Smith

RP1 Program Leader, EOSSS

Professor Craig Smith is the CEO and technical director for EOS Space Systems (EOSSS). He leads a multi-disciplinary team of science and engineering innovators developing lasers, beam directors, precision timing systems, sensors, and control systems for the laser tracking products. Prof. Smith has also held positions within EOS as CEO EOS Technologies (the US subsidiary of EOS) and Head of Research and Development. Prior to joining EOS, Prof. Smith was a Senior Research Fellow at the Australian Defence Force Academy. There he developed novel techniques for imaging-polarimetry and spectro-polarimetry at thermal infrared wavelengths. These remote sensing techniques are able to provide materials characteristics from the thermal signature of an object. Prof. Smith has lectured in Physics and Electronics and Military Ballistics and is an Adjunct Professor at RMIT University. He obtained Bachelors and PhD degrees in Physics from the University of Melbourne.

Assoc Prof. François Rigaut

Adaptive Optics, ANU

Associate Professor François Rigaut obtained his PhD from University of Paris 7 in 1992 on the first Adaptive Optics (AO) system for astronomy, COME-ON, then developed in Europe and used at the ESO La Silla observatory. Since then, Dr Rigaut has been involved in the technological and theoretical developments and promotion of AOs at several institutes, the Canada France Hawaii Telescope, the European Southern Observatory and the Gemini Observatory; and through various instruments: PUEO, NAOS, Altair and lately the Gemini multi-conjugate AO system GeMS, the first and only Laser Guide Star Multi-Conjugate AOs system. Since January 2012, Dr Rigaut works at the ANU Research School of Astronomy and Astrophysics, where he now leads AO activities, concentrating on two main projects: a Laser Tomography AO system for the Giant Magellanic Telescope and an AO prototype for conditioning of laser beams used in space debris tracking, nudging and de-orbiting.



Dr James Webb

Guide Star Laser Science, EOSSS



Dr James Webb is EOSSS's instrument scientist, where he applies a diverse range of skills accumulated over more than 20 years in numerous defence, academic, commercial and industrial Research and Development roles. After a period with the Royal Australian Air Force and graduating as an electronics engineer, he founded and worked in a series of start-ups developing high speed inkjet printers, smart card readers, image compression and cryptographic utilities. Following further studies in explosives, adaptive and quantum optics he spent time as a researcher with UNSW, then in Hawaii as an electronics engineer at the UKIRT and JCMT telescopes. Upon returning to Australia, Dr Webb resumed consulting in the areas of medical and security product development and defence communications while employed as a Research and Development engineer in the field of high accuracy positioning. He is currently focussed on the creation of new telescope control systems and the EOSSS/SERC guide star laser.

2.0 RESEARCH

2.1 CHIEF INVESTIGATORS



Prof. Kefei Zhang

RP2 Program Leader, RMIT University

Professor Kefei Zhang is the founder and director of the Satellite Positioning for Atmosphere, Climate and Environment (SPACE) Research Centre and the Satellite Positioning and Navigation (SPAN) Laboratory at RMIT University. He has over 25 years of research experience in satellite positioning, geodesy and geospatial sciences with over 250 peer-reviewed publications in these fields. Prof. Zhang's current research interest is primarily involved in algorithm development and innovative applications of GNSS/GPS technologies for high-accuracy positioning, atmospheric studies (e.g. radio occultation, space weather, climate change, weather and environment), space situational awareness (e.g. space debris tracking, surveillance and collision warning and orbit determination) and people mobility and object tracking.

Dr Robert Norman

Atmospheric Signal Propagation, RMIT University

Dr Robert Norman is a Senior Research Fellow and member of the SPACE Research Centre, and the SPAN Laboratory at RMIT University. Prior to joining RMIT, Dr Norman held research positions at La Trobe University before moving on to UK defence research agency QINETIC to work in the area of high frequency beyond line of sight communications. Dr Norman then returned to Australia to take up another research position at La Trobe involving Telstra and Lockheed Martin subsidiary RLM, working on the Jindalee Over the Horizon radar. Dr Norman's current research interests are in laser signal propagation using geometrical optics and atmospheric density modelling using GNSS radio occultation. In addition to leading the SERC research team at RMIT, Dr Norman is primarily responsible for the atmospheric density modelling and ray tracing research streams.



Dr Brett Carter

Space Weather, RMIT University



Dr Brett Carter received a BSc in Space Physics with First Class Honours from La Trobe University before going on to complete a PhD specialising in high-frequency radar backscatter from plasma irregularities in the high-latitude, auroral and sub-auroral latitudes. Dr Carter's main specialisation is in ionospheric plasma instabilities, which is important for many real-world applications. Recently, Dr Carter has turned towards understanding the interactions between the charged particles and neutrals in the upper atmosphere due to the important role they play in understanding atmospheric drag on objects in low-Earth orbit.

2.0 RESEARCH

2.1 CHIEF INVESTIGATORS



Dr Steve Gehley

Orbit Determination, RMIT University

Dr Steve Gehley grew up near Boston, Massachusetts in the USA before moving to Los Angeles to pursue his tertiary studies. Dr Gehley completed his undergraduate degree at the University of Southern California, graduating with a BSc in Aerospace Engineering. Dr Gehley then landed every aerospace engineers dream graduate job, working at Northrop Grumman. But Dr Gehley wasn't done yet, as he took on the juggling act of five years of full-time work at Northrop while studying and completing his Master's degree at the University of Southern California before moving to Colorado to pursue his PhD specialising in orbit determination and space situational awareness. His dissertation research focused on multi-target estimation for SSA and other related applications such as sensor allocation and initial orbit determination.

Dr James Bennett
RP3 Program Leader, SERC

Dr James Bennett has over five years' experience in Astrodynamics and over ten years' experience in industrial applied mathematics, after obtaining his PhD in Applied Mathematics from RMIT University.

Dr Bennett is a Western Pacific Laser Tracking Network (WPLTN) representative to the International Laser Ranging Service (ILRS) Governing Board. His research interests include orbit determination and prediction, conjunction assessments, applied mathematics, debris object characterisation, optical and laser tracking, and singular and regular perturbation methods.



Dr Marek Möckel
High Performance Computing, SERC



Dr Möckel studied Computer Science at Braunschweig University of Technology, spending the vast majority of his time within the Linux and open source community. Before joining SERC, Dr Möckel worked at Siemens' rail automation department developing software for railroad traffic management. Dr Möckel says his practical knowledge in space research is thanks to his work in developing video games in the open source community. Dr Möckel wanted to work for SERC as he says it gave him an opportunity to put his research to practical use whilst working in a field that ensures the safe use of one of the Earth's natural resources.

2.0 RESEARCH

2.1 CHIEF INVESTIGATORS



Dr Daniel Kucharski

Satellite Spin Dynamics, SERC

Dr Daniel Kucharski studied mechatronics at Warsaw University of Technology, with a particular focus on the use of laser technology for nano-scale measurements of length and roughness. Dr Kucharski went on to study a joint PhD program with the Polish and Austrian Academies of Science, specialising in Satellite Laser Ranging (SLR) and spin determination of artificial satellites. At that time the only system able to deliver spin determination data was located in Austria, and through his studies, Dr Kucharski developed new methods for attitude and spin determination of laser tracked objects. Dr Kucharski has developed collaborations with colleagues at Borowiec SLR station in Poland, the Space Research Institute in Austria, Hitotsubashi University and National Institute of Information and Communication Technology (NICT) in Japan and the Korean Astronomy and Space Science Institute.

Dr Sven Flegel

Non Linear Covariance Propagation, SERC

Dr Sven Flegel studied Mechanical Engineering at the Technische Universität in Braunschweig, Germany, before shifting focus to aerospace where he specialised in space studies. Dr Flegel's doctoral thesis "Multi-Layer Insulation as Contribution to Orbital Debris" studied the mechanisms behind how insulating foils from spacecraft could separate to become part of the debris environment and how their orbits could evolve over time. Dr Flegel worked at the Institute of Space Systems, developing a suite of comprehensive space debris cataloguing software programs for the European Space Agency (ESA). He subsequently worked as a Research Scientist at the Fraunhofer Institute for High Frequency Physics and Radar Techniques, where he developed software for the estimation of uncertainties in radar measurements for a range of radar types. Dr Flegel also performed an extensive analysis of the potential benefits of performing debris detection campaigns wherein objects with orbit inclinations below 50° could be observed. This led to the first debris detection campaign of the Tracking and Imaging Radar (TIRA) system in December 2015, in which the antenna was pointed in a southerly direction, rather than due east.



Mr Matthew Bold

RP4 Program Leader, Lockheed Martin



Mr Matthew Bold is a Principle Researcher with the Lockheed Martin (LM) Space Systems Company Advanced Technology Center in Palo Alto, California, USA. His undergraduate studies were in physics and mathematics at the University of Dayton and graduate studies in high energy particle physics at Arizona State University. Since 1996, Mr Bold has been studying the propagation of high energy lasers through the atmosphere with particular interest in the modelling of atmospheric optical turbulence and the performance modelling of adaptive optics systems. For the last ten years Mr Bold has been involved in the space situational awareness research efforts at the UKIRT Telescope in Hawaii and the LM SPOT telescopes in Santa Cruz California. He is involved with the SERC Remote Manoeuvre research project assisting with system engineering and performance modelling and simulation.

2.0 RESEARCH

2.1 CHIEF INVESTIGATORS



Mr Jeffrey Allen

High Power Laser Propagation, Lockheed Martin

Mr Jeffrey Allen received his B.S. and M.S. in pure mathematics from the University of Wisconsin with a concentration on real, functional and numerical analysis. His thesis work focused on increasing the efficiency of a numerical PDE solver by incorporating Krylov subspace methods. In the summer during graduate school he was an intern at the Advanced Technology Centre where he was introduced to Fourier optics and interferometry. After completing his MS in 2014, he joined the Advanced Technology Centre full time and has developed algorithms in areas including image processing, fringe tracking, and sensor modelling. Over the past year his main interests have been modelling atmospheric propagation and adaptive optics. Mr Allen's role in the SERC program has been modelling the high energy laser beam propagation and AO system to estimate the delivered irradiance on a low earth orbit (LEO) target.

Prof. Daniel Shaddock

Phased Laser Beam Combining, ANU

Professor Daniel Shaddock is a Professor in Physics at ANU. His main area of expertise is precision measurements using laser interferometry. Before joining the ANU he was a Director's Fellow at NASA's Jet Propulsion Laboratory where he worked on the Laser Interferometer Space Antenna mission. Prof. Shaddock leads Australia's involvement in the Gravity Recovery And Climate Experiment (GRACE) follow-on mission to map the Earth's gravity and was part of the team that detected gravitational waves with the Advanced Laser Interferometer Gravitational-Wave Observatory (LIGO) project. He is also the Founder and CEO of the start-up Liquid Instruments which makes high-end test and measurement instruments.



Dr Francis Bennet

Adaptive Optics, ANU

Dr Francis Bennet holds a degree with first class honours in Science (Physics) from ANU and completed his PhD in Physics at ANU in 2011. He is currently developing AOs with the Research School of Astronomy and Astrophysics at the Mount Stromlo Observatory in Canberra, Australia, as part of ANU's partnership with the Giant Magellan Telescope project. He is also developing AO systems in partnership with EOSSS to improve their current space debris tracking program as part of SERC's Research Program (RP). Dr Bennet's current research interests include AOs, astrophotonics, laser physics, and optical design.

2.0 RESEARCH

2.2 RESEARCH PROGRAMS

SERC research

is organised around four interdependent research themes



2.0 RESEARCH

2.2 RESEARCH PROGRAMS

Tracking, characterising and Identifying Objects in Orbit

Research Program 1

Professor Craig Smith, Research Program Leader

This RP will develop innovative techniques of active and passive object tracking to provide sufficient accuracy for orbit propagation and conjunction prediction.

The Active Track in LEO research project will investigate and develop non-terminator acquisition and tracking of debris objects. The research will also develop novel techniques to detect and provide precision orbit determination for new (currently un-catalogued) objects.

6 projects



3 participants



22 researchers



6 students



innovative techniques of active and passive object tracking to provide sufficient accuracy for orbit propagation and conjunction

Orbit Determination and Predicting behaviours of Space Objects

Research Program 2

Professor Kefei Zhang, Research Program Leader

To predict future collisions between space objects, the orbit predictions that properly account for the variable space environment, e.g. the Earth's gravity field, atmospheric drag, solar magnetic disturbances and other perturbing forces, are required.

The primary objective of RP2 is to develop advanced high precision orbit propagators.

2 projects



2 participants



12 researchers



5 students



orbit predictions that properly account for the variable space environment are required

2.0 RESEARCH

2.2 RESEARCH PROGRAMS

Space Asset Management

Research Program 3

Dr James Bennett, Research Program Leader

This RP will develop techniques, algorithms and databases to predict and avoid potential collisions. It will provide a transparent and rational means to make decisions about asset management and how best to optimise assets and preserve the space environment.

A major focus will be the development of systems that allow multi-national contributions to space object catalogues and a global distribution of asset management.

2 projects



2 participants



13 researchers



1 student



systems that allow multi-national contributions to space object catalogues and a global distribution of asset management

Preservation of the Space Environment

Research Program 4

Mr Matthew Bold, Research Program Leader

This RP will develop AO capabilities that allow high intensity laser beams to be propagated through the atmosphere and is an enabling technology for remote manoeuvre.

This RP will also develop high power laser technologies to be used in photon pressure experiments and develop techniques to combine and phase multiple lasers for increased power, beam shaping and beam control.

3 projects



3 participants



22 researchers



6 students



momentum properties of light make it possible to effect small orbit changes when high power laser beams illuminate a debris target

2.0 RESEARCH

2.2.1 RESEARCH PROGRAM 1

Tracking, Characterising and Identifying Objects in Orbit

Project Participants

Australian National University

EOS Space Systems

*National Institute for Information and
Communications Technology (Japan)*

Lockheed Martin

Research Snapshot for 2016

- R1.1 Develop passive and active track sensors
- R1.2 Develop a database for historical recall of observations and object characterisation
- R1.3 Debris Characterisation by High Resolution Imagery
- R1.4 Extend Active Laser tracking to Objects at Geostationary Ranges.
- R1.5 Develop Adaptive Optics Astrometry Capabilities

2.0 RESEARCH

2.2.1 RESEARCH PROGRAM 1

R1.1 Develop Passive and Active Track Sensors

Project lead: EOSSS

Participants: EOSSS, ANU

Researchers: Craig Smith, Ian Richie, Patrick Burns, Mark Blundell

This project will design and develop passive and active track sensors for objects at geostationary orbits. This includes technologies for telescopes, beam directors, detectors, lasers, timing systems, optical systems, command and control software.

The dome for the 75cm GEO tracker has been received and test assembly has been completed. The telescope dome ringwall has also been manufactured. Plans for the installation of the GEO tracker telescope at the Mount Stromlo Observatory are being prepared for ANU Facilities & Services and National Capital Authority (NCA) approval. The spectrometer preliminary design has been completed and an appropriate prism is being sourced. The Wide Field of View (WFOV) telescope prototype camera has been assembled and tested. Testing has resulting in some re-work which is now in progress. Once NCA approval has been obtained, construction of the telescope on-site can commence.

All milestones on this project have been achieved and work is 18 months ahead of schedule.



Figure 01: EOSSS telescope manufacturing facility, Queanbeyan.

R1.2 Develop a Database for Historical Recall of Observations and Object Characterisation

Project lead: EOSSS

Researchers: David Kooymans, James Bennett, Alex Pollard

Participants: EOSSS, LM, SERC

Non-Participant Collaborators: Royal Observatory Edinburgh

A database of target track, orbit data, and observable signatures with historical reach back to all past observations will be developed in this project for historical recall of observations and object characterisation.

SERC is pursuing two avenues to deliver the space situational awareness (SSA) observations database output; development of an in-house tailored database solution, and sourcing a database already in existence. LM have already built an object catalogue database for the US Government (iSpace).

An agreement among Participants is being developed on access requirements and data housing location.

R1.3 Debris Characterisation by High Resolution Imagery

Project lead: ANU

Researchers: Francis Bennet

Participants: ANU, EOSSS

This output will draw on the RP4 AO and RP1 sensor developments to obtain high resolution (diffraction limited imagery) of satellites and space debris. Having information about geometry, stability and surface condition allows better estimation of orbit parameters in RP2. SERC will apply compact AO technology, and a laser guide star (LGS), similar to commercial AO systems recently built by ANU.

2.0 RESEARCH

2.2.1 RESEARCH PROGRAM 1

The commercial ANU project team, in association with EOSSS, recently achieved images at, or close to, the diffraction limit to the EOSSS-1.0m telescope (0.25" FWHM). This program is considered as a pathfinder for the SERC AO programs. Design of a Stereo-Scidar has also commenced. This will be used to perform a site testing campaign to inform the various AO system designs. This project will remain on schedule until the critical design review (CDR) has been completed within late 2016.

R1.4 Extend Active Laser tracking to Objects at Geostationary Ranges

Project lead: EOSSS

Researchers: Yue Gao, Yanji Wang, Francis Bennet

Participants: ANU EOSSS, LM

Tracking accuracy at GEO altitudes is compromised because GEO tracking is limited to passive sensors. With passive sensors, the resolution on the sky decreases with range. At LEO, resolution is of the order of ~1m, whereas the resolution at GEO altitudes is ~100m. This project will design for a demonstration of capability to use an active laser tracker at GEO providing 1m resolution. This will require developing high performance AO systems, high power tracking lasers, beam directors, beam shaping, laser phasing, and algorithms.

Testing of optics at high laser power has been completed. Performance data of the SPOT tracking systems LM have implemented have been used to support the AO system design. CoDR was passed on June 15 for the so called AOTP (AO Tracking & Pushing) system. PDR will follow suit in August, and CDR in November/December.

As this system is based on the already existing systems developed for the AO activities, this output has been achieved.

R1.5 Develop Adaptive Optics Astrometry Capabilities

Project lead: ANU

Researchers: François Rigaut, Celine d'Orgeville

Participants: ANU, EOSSS, LM

The program is developing an AOs systems that can reduce the Point spread function of stars and targets (diffraction limit) so that higher accuracy astrometric solutions can be made to determine the absolute position on the sky of the GEO target. This will require developing high performance AO systems, sensors, calibration systems and algorithm development.

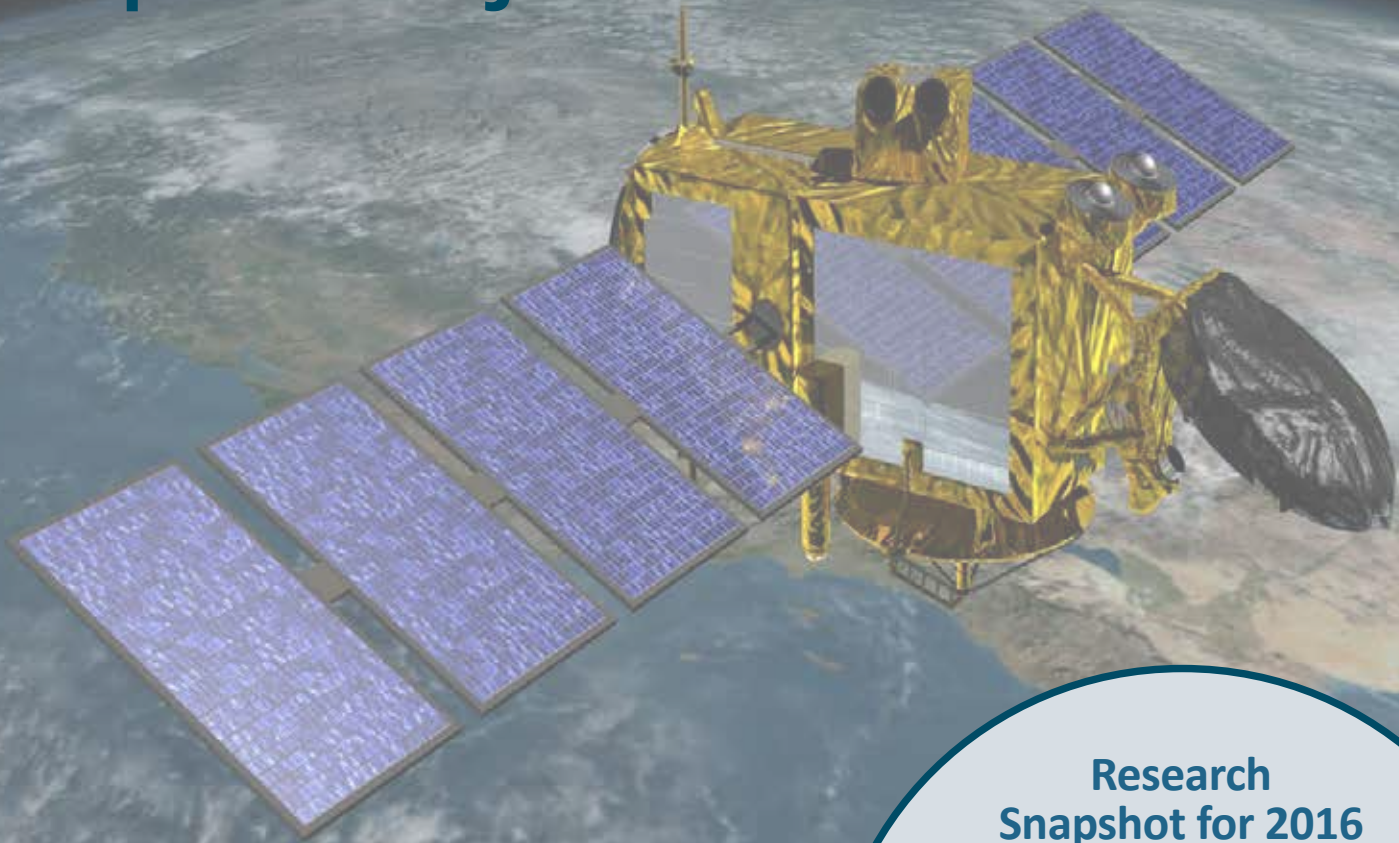
We have implemented an AO model into performance modelling tools to provide inputs to astrometric capability primarily through a trade of AO performance versus blur spot reduction. Dr Piotr Piatrou has submitted a paper for *Acta Astronomica* to present the method, concept, and expected performance of the GEO GAIA method. This was also used as the input for the design of the AO imaging system in R1.3.

This milestone will be marked as achieved once satisfactory peer review comments have been received.

2.0 RESEARCH

2.2.2 RESEARCH PROGRAM 2

Orbit Determination and Predicting Behaviours of Space Objects



Research Snapshot for 2016

R2.1 Develop Intelligent Systems for Real-Time Precision Orbit Determination (POD) for 'Controlled' Satellites

R2.2 Development of Reliable Orbit Determination (ROD) Algorithms and Software

Project Participants

*RMIT University
National Institute for Information and Communications Technology (Japan)*

2.0 RESEARCH

2.2.2 RESEARCH PROGRAM 2

R2.1 Develop Intelligent Systems for Real-Time Precision Orbit Determination (POD) for 'Controlled' Satellites

Project lead: RMIT

Researchers: Robert Norman, Yang Yang, Brett Carter

Participants: RMIT, NICT

This research program is developing real-time POD software platforms that incorporate attitude modelling of 'controlled' satellites orbiting at a range of altitudes. The program will develop methods to accurately determine atmospheric mass density modelling through an improved understanding of the effects of perturbing influences. The groundwork into developing new POD capabilities has been achieved and the orbit uncertainty associated in the orbit propagation process quantified using polynomial chaos expansion (PCE). A new PCE-based particle filter has been proposed and will be applied in the orbit determination. Schmidt-Kalman filters have been studied to consider the uncertainties associated with some dynamic parameters in the orbital models, so that POD precision could be improved. POD solutions have been generated using GPS only observations based on Bernese software. Implementation of combined GPS/SLR based POD has commenced. This output will be marked as achieved on algorithm design and development of theory and software has been completed instead of commenced as written.

R2.2 Development of Reliable Orbit Determination (ROD) Algorithms and Software

Project lead: RMIT

Researchers: Steve Gehley, Jerome Daquin

Participants: RMIT, NICT

Advanced ROD platform for 'uncontrolled' space objects. The ROD software platform being developed comprises versatile orbit determination algorithms that employ data from a variety of different sources; e.g. two-line elements data and satellite laser ranging. The design for software development commenced from early 2015. Good progress has been made; and refinement is key in areas of development is still in progress. Most of the work has been successfully completed. For example, simulation of laser propagation paths traversing through different atmospheric and ionospheric models has been completed. The identification of useful geomagnetic activity forecasts is complete, and software development towards outputting atmospheric mass density (AMD) model information has continued. The potential benefit of using GPS RO data in data assimilation into physics-based thermosphere-ionosphere models has been identified and is being investigated. Investigation of the role of the ionosphere on atmospheric density modelling and satellite drag is underway. Design for software development has commenced and will be formally achieved imminently.

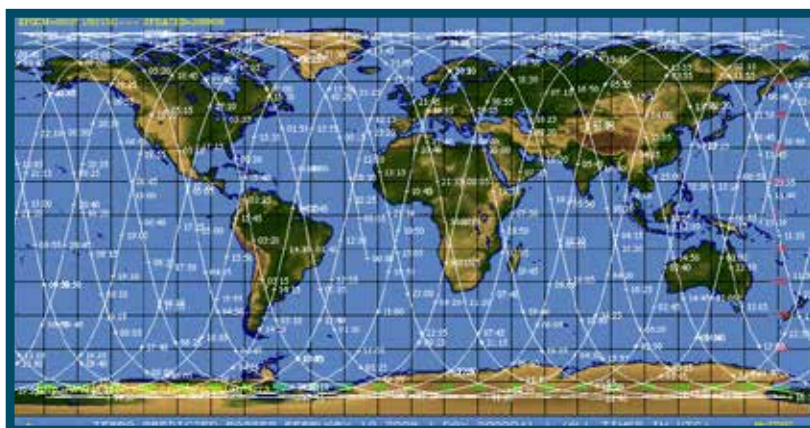


Figure 02: Orbit track diagram. Credit: Christian S. Perone

2.0 RESEARCH

2.2.3 RESEARCH PROGRAM 3

Space Asset Management

Project Participants

SERC

Optus Satellite Systems

Research Snapshot for 2016

R3.1 Develop a special Satellite Object Catalogue

R3.2 Develop Conjunctions Analysis and Threat Warning (CATW)

2.0 RESEARCH

2.2.3 RESEARCH PROGRAM 3

R3.1 Develop a special Satellite Object Catalogue (SOC)

Project lead: SERC

Researchers: James Bennett, Daniel Kucharski, Michael Lachut, Marek Möckel, Sven Flegel, David Kooymans

Participants: SERC, Optus

A core function of the research program is to develop a SOC. This RP is developing techniques, processes, data formats and distribution methods to develop a SOC using global data. The 1.8m Mount Stromlo telescope mount has been studied in detail and improvements in mount modelling have been achieved. This is very important for when astrometric corrections and laser observations are unavailable since the observation accuracy is mount model dependent. A detailed knowledge of the complex tracking systems has been gained and data quality assessments have been completed. This analysis is imperative for the catalogue accuracy since erroneous data could corrupt the orbital elements generated from the data. The technique will be applicable globally. Subsequently this will affect the reliability of conjunction assessments. A new data format for handling high precision pointing observations has been created in collaboration with RP1. A method has been developed to estimate object area-to-mass ratio using long-term TLE data, focussing on the regions where drag is no longer the dominant non-gravitational perturbation force. Solar radiation effects on orbiting objects has been analysed. A reliable area-to-mass ratio is critical for reliable orbit determinations, predictions and for conjunction assessments where observation data is sparse. A new method termed "Phase Dispersion Minimisation" has been developed to determine spin period of orbiting objects. This method will outperform frequency analysis and yields a unique solution for slowly spinning satellites. The analysis of data formats and sensor data integration output has been achieved.

R3.2 Develop Conjunctions Analysis and Threat Warning (CATW)

Project lead: SERC

Researchers: James Bennett, Marek Möckel, Sven Flegel, Daniel Kucharski, Michael Lachut

Participants: SERC, Optus

SERC is developing a conjunction analysis capability system for all objects (all-on-all conjunction analysis) in the Satellite Object Catalogue and provide alerts to subscribers. The SERC conjunction system will also distribute priority tasking to sensors in the SOC network to provide increased tracking and updating for serious potential collision prospects. The conjunction analysis and sensor tasking feedback loop will be optimised to minimise the risk of a real collision systems.

Algorithms for conjunction analysis and optimised sensor scheduling are in development. A new GPU-based conjunction assessment software suite has been developed in C++. Comparisons have been carried out comparing CPU and GPU all-on-all conjunction assessments speeds and the new GPU code significantly outperforms the CPU version. Algorithms to minimise telescope slew times have been developed. A GUI has been created with an overlay on the ANU all-sky camera at Mount Stromlo. This will be used to estimate cloud cover and update the telescope track to favour clear region. Methods have been developed to estimate cloud cover based on sky brightness. This is a single-node optimisation which will assist with the network optimisation. Methods are in development for network scheduling based on information gain.

This output has been achieved.

2.0 RESEARCH

2.2.4 RESEARCH PROGRAM 4

Preservation of the Space Environment

Project Participants

ANU

EOS Space Systems

Lockheed Martin

*National Institute for Information and
Communications Technology (Japan)*

Research Snapshot for 2016

- R4.1 Development of Adaptive Optics
- R4.2 Development of High-Power Lasers
and Phased Laser Beam Combining
- R4.3 Demonstration of Remote Manoeuvre
of Space Debris and Photon Pressure

2.0 RESEARCH

2.2.4 RESEARCH PROGRAM 4

R4.1 Development of Adaptive Optics

Project lead: ANU

Researchers: Francois Rigaut, Francis Bennet, Craig Smith

Participants: ANU, EOSSS, LM

This research program will develop leading edge AO capabilities that allow high intensity laser beams to be propagated through the atmosphere and is an enabling technology for remote manoeuvre.

The AOTP system CoDR was passed on June 15 with Participants from EOSSS, ANU and LM. The PDR will follow in August, and CDR in November/December. The design of a Stereo-Scidar is well progressed. This will be used for the RP1 AOI and the RP4 AOTP programs to perform a site testing campaign at the 1.8m to inform the AO system designs. First light is expected around July-August. LM has completed configuration and has started trade studies on our OPAL wavefront propagation tool to compare with other simulations. LM has worked with ANU to begin site characterisation of the Mount Stromlo site for propagation conditions including temporal characterisation to aid in demonstration planning. Some of the turbulence conditions are more severe than anticipated and impact to performance is being evaluated.

The SERC/EOSSS guide star laser design has been completed. The build of hardware and control software is underway. Work is progressing on locking the oscillator cavity channel and significant progress made in stabilising the laser. Work is now moving to the power amplifiers. The oscillator is being mechanically re-packaged to improve physical stability. Full operational capability is expected in Q1 2018.

Work is progressing on the real time control design for new hardware/software developments. LM has

commenced trade studies on our OPAL wavefront propagation tool to compare with other simulations. Seeking atmospheric characterization data for Mount Stromlo. Important Greenwood frequency data will drive control system performance. All outputs under R4.1 are classified as on schedule at the highest level, though some individual milestones have not been met. There are no major anticipated issues with SERC meeting the outputs as listed.

R4.2 Development of High-Power Lasers and Phased Laser Beam Combining

Project lead: EOSSS

Researchers: Yue Gao, Amy Chan, Yanjie Wang, Daniel Shaddock, Matthew Bold

Participants: ANU, EOSSS

High-power lasers and phased laser beam combining: This research program will develop high power laser technologies to be used in photon pressure experiments and also develop techniques to combine and phase multiple lasers for increased power, beam shaping and beam control.

Options for providing the required laser power are being assessed. Systems engineering indicates that more than 10kW will be required to effect orbit manoeuvre so SERC is looking at options to increase laser power, including combining multiple beams to achieve higher power. LM are working with internal property control and export control experts to evaluate the possibility to move a 10kW laser to Mount Stromlo for the demonstration. The full TAA licence has been submitted to the Department of State. The laser was considered as part of this licence. Atmospheric characterisation data for Mount Stromlo will feed into the simulations and important Greenwood frequency data will drive control system performance.

2.0 RESEARCH

2.2.4 RESEARCH PROGRAM 4

This research output will not be required before 2020 as SERC is looking to use an existing laser instead of designing and building one from scratch. As the laser is yet to be delivered, the output is marked as in-progress. The core research effort may still be required to produce high laser power outputs above 10kW.

R4.3 Demonstration of Remote Manoeuvre of Space Debris and Photon Pressure

Project lead: LM

Researchers: Matthew Bold, James Mason, Ben Greene, Craig Smith

Participants: EOSSS, LM

This program combines the outputs of active tracking, orbit computation and beam propagation through the atmosphere to make small but measureable changes to an orbit. The aim of the project is a demonstration of a practical active collision avoidance system using photon pressure.

Orbit manoeuvre options have been analysed with the view to determine how likely it will be to see and

measure an orbit change. As a result, it has been concluded that to perform a quantifiable experiment it would be highly beneficial to put a controlled (and instrumented) target into space, rather than choose an uncontrolled object from the existing debris cloud.

Following the review of research programs undertaken by Research Management Committee, a new research program will be developed to design and launch up to 3 cubesats with appropriate instrumentation on board to meet the requirements of the orbit manoeuvre.

LM has hired extra resources to the orbital mechanics team and has started development of an orbit manoeuvre model. Lockheed has completed installation of configuration of the STK toolkits that support this analysis. Initial trade studies have started focusing on types of orbits and A/M parameters for different classes of engagement. Lockheed is currently collaborating with the University of Arizona on this.

This output has effectively been achieved but refinements are needed to mark it as fully achieved.



Figure 03: Space debris tracking at the EOS Space Research Centre, Mount Stromlo.

2.0 RESEARCH

2.3 PUBLICATION CROSS-SECTION

ORBIT DETERMINATION USING SLR DATA FOR STSAT-2C: SHORT-ARC ANALYSIS

Kim, Y.-R. , Park, E., Kucharski, D., Lim, H.-C.

Journal of Astronomy and Space Science

In this study, we present the results of orbit determination (OD) using satellite laser ranging (SLR) data for the Science and Technology Satellite (STSAT)-2C by a short-arc analysis. For SLR data processing, the NASA/GSFC GEODYN II software with one year (2013/04- 2014/04) of normal point observations is used. As there is only an extremely small quantity of SLR observations of STSAT-2C and they are sparsely distribution, the selection of the arc length and the estimation intervals for the atmospheric drag coefficients and the empirical acceleration parameters was made on an arc-to-arc basis. For orbit quality assessment, the post-fit residuals of each short-arc and orbit overlaps of arcs are investigated. The OD results show that the weighted root mean square post-fit residuals of short-arcs are less than 1 cm, and the average 1-day orbit overlaps are superior to 50/600/900 m for the radial/cross-track/along-track components. These results demonstrate that OD for STSAT-2C was successfully achieved with cm-level range precision.

FUTURE SPACE DEBRIS TRACKING REQUIREMENTS

Smith, C.H. Greene, B.

33rd AIAA International Communications Satellite Systems Conference

Space debris collision avoidance requires accurate space debris orbits, to allow confident manoeuvre of an operational satellite to avoid a predicted collision. Operational spacecraft do not have sufficient on-board fuel to manoeuvre with the frequency, and for the long distances, required by the large uncertainties or errors in space debris positions as currently available. There is a significant demand for larger and more accurate space debris catalogues for this reason. Emerging technologies offer the possibility of moving space debris to avoid a collision, either as an alternative to moving an operational spacecraft, or to prevent debris-debris collisions which would add to the overall space debris burden. However any manoeuvre of space debris requires very high levels of confidence that the new, contrived space debris orbit is less likely to cause harm than the old/current orbit. This requires even higher levels of space tracking capability and capacity than have been projected for conventional collision avoidance purposes. We will discuss emerging space tracking capabilities and the prospects of meeting the space tracking and catalogue requirements for both these classes of activity.

INTERPLANETARY SHOCKS AND THE RESULTING GEOMAGNETICALLY INDUCED CURRENTS AT THE EQUATOR

B. A. Carter, E. Yizengaw, R. Pradipta, A. J. Halford, R. Norman, K. Zhang

Geophysical Research Letters

Geomagnetically induced currents (GICs) caused by interplanetary shocks represent a serious space weather threat to modern technological infrastructure. The arrival of interplanetary shocks drives magnetosphere and ionosphere current systems, which then induce electric currents at ground level. The impact of these currents at high latitudes has been extensively researched, but the magnetic equator has been largely overlooked. In this paper, we investigate the potential effects of interplanetary shocks on the equatorial region and demonstrate that their magnetic signature is amplified by the equatorial electrojet. This local amplification substantially increases the region's susceptibility to GICs. Importantly, this result applies to both geomagnetic storms and quiet periods and thus represents a paradigm shift in our understanding of adverse space weather impacts on technological infrastructure.

SINGLE DETECTOR STEREO SCIDAR FOR MOUNT STROMLO

Doris Grosse, Francois Rigaut, Francis Bennet

SPIE Astronomical Telescopes and Instrumentation

Laser ranging measurements and satellite imaging are conducted at Mt Stromlo as part of the Space Environment Management CRC to support debris tracking and orbit prediction. Atmospheric turbulence lead to distortions in the measured data. Adaptive optics (AO) systems counteract those distortions and improve the resolution of the laser ranging measurements and satellite imaging systems. To assist in the design of the AO Systems, we need to gather information on the atmosphere at Mt Stromlo: r_0 , τ_0 , and the turbulence C_n^2 profile, so that the turbulence at the mirror and dome, ground layer and the free atmosphere can be distinguished. The SCIntillation Detection And Ranging (SCIDAR) Technique is used to measure C_n^2 . With this technique the scintillation of two stars is measured and their autocorrelation function is computed, providing a measurement of the turbulence profile. We introduce a new Stereo-SCIDAR system separating the scintillations from the double star, but using only one single detector. We show first, preliminary results of this system and investigate its feasibility for further development.

2.0 RESEARCH

2.3 PUBLICATION CROSS-SECTION

SERC Publications

SERC RPs produced a total of 50 publications in 2015/16.

This includes one book chapter, 11 refereed journal papers and two refereed conference papers. In addition to this, a further 36 publications and reports for end-users were produced. A list of all SERC publications, both formal and other publications is provided at Appendix 1.

2.0 RESEARCH

2.4 EDUCATION AND TRAINING

SERC has a strong focus on education and training and is committed to recruiting the best and brightest students to develop the next generation of space industry professionals. During the reporting period, SERC awarded 13 Higher Degree by Research (HDR) top-up scholarships and two undergraduate scholarships. In addition, four HDR scholarships that were awarded in the previous reporting period, were funded for a second year, bringing the student cohort to 17 postgraduate and two undergraduate students.

Implementation of the aggressive recruitment strategy outlined in the 2014/15 annual report has resulted in SERC exceeding its 2015/16 education milestone (eight postgraduate students enrolled) by more than 100%. SERC is well placed to meet its 30 June 2019 scholarship and training obligations. A full list of the 2015/16 SERC students and research projects is provided Appendix 2.

Student Involvement in SERC Activities

SERC students are an integral part of the SERC Research Program and are included in all SERC events and

activities. Throughout 2015/16, SERC continued to provide enhanced education and training opportunities for SERC students including participation in the following activities:

- **Guest lecture by international subject matter expert on Space Situational Awareness:** SERC joined with the University of New South Wales (ADFA) to host a guest lecture by Prof. Moriba Jah. This afforded SERC researchers and students the opportunity to learn from a renowned expert in astrodynamics-based SSA sciences and technologies.
- **Introduction to Astrodynamics workshop:** SERC hosted visiting Prof. Jizhang Sang from Wuhan University to deliver a “Introduction to Astrodynamics” workshop which was attended by 30 SERC researchers and students. The workshop was initiated after an education audit identified the need for an intensive orbit determination and propagation workshop. Prof. Sang is a highly regarded subject matter expert and delivered an exceptional program over a five-day period.

2.0 RESEARCH

2.4 EDUCATION AND TRAINING

- **Research presentations to the SERC Research Management Committee:** During the November and May Research Colloquia, SERC students were provided with the unique opportunity to present their research topics to members of the Research Management Committee. Students received direct feedback from Committee members and some were invited to contact Committee member's offline for further advice and guidance. SERC will build on this pilot program and schedule a student clinic with Research Management Committee members at the next Research Colloquium.
- **Attendance at International Industry Conferences:** Four SERC students were invited to present papers and/or posters at the Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) in Hawaii. AMOS is regarded as the premier space surveillance conference in the world. In addition, two students were accepted to present papers at the International Workshop on Shock Tube Technology hosted by the Institute of Aerodynamics and Flow Technology in Germany. Attendance at international events and symposia provides students with exposure to international trends and developments and the opportunity to learn from and engage with world leaders in space technologies.

End-user Interaction with Students

As an industry-led CRC, end-user requirements and commercialisation prospects are highly valued and drive a great deal of the research activity.

EOSSS is the lead organisation involved in RP1. In this capacity, EOSSS contributes to the supervision of students involved in this research program. Similarly LM and Optus are involved with RP4 and

3 respectively, creating opportunities for students to interact with and understand the requirements of these end-users.

In addition, SERC is conducting ongoing discussions with end-users, space research institutions and industry to identify and negotiate internship opportunities for SERC graduates. It is anticipated that as SERC research matures, exciting opportunities will be available nationally and internationally for SERC students.

Community Outreach

In December 2015, SERC sponsored and participated in the Australian Science Teachers Association STEM X Academy. The STEM X Academy is a five-day residential professional learning program for Australian science, technology, engineering and mathematics teachers, where participants are exposed to new approaches to teaching STEM in Australian classrooms. The SERC Chief Executive Officer delivered a presentation on the global issue of space debris and the work SERC is doing to address this problem. This session was extremely well received and has inspired a number of the teachers to include space debris management as part of their environmental management curriculum. One gifted and talented year 5/6 class has been so inspired that they have interviewed Dr Greene via Skype with the intent of writing his biography. Dr Greene reported this interview as being one of the most gruelling interviews he has been subjected to.

Figure 04: Teachers attending SERC sponsored STEMX Event December 2015.



STUDENTS INVOLVED WITH

SERC Research

Degree	Name and University	Research topic	Financial assistance
PhD	P. Sibley, ANU	Laser Written Waveguides for an Optical Phased Array Head	Supplementary
BSc (Hons)- Applied Sci	S. Le May, RMIT	Modelling the future evolution of the orbital debris population	Undergraduate
PhD	C. He, RMIT	Precise thermospheric density correction for robust orbit determination and prediction of low-Earth-orbit objects	Supplementary
PhD	M. Afful, RMIT	Space Debris Characterisation for Reliable Orbit Determination and Prediction	Supplementary
PhD	T. Kodikara, RMIT	Enhancing Atmospheric Mass Density Modelling for Space Situational Awareness	Supplementary
PhD	K. Damm, UQ	Multipoint, Multi-objective geometric optimisation of a hypersonic launch vehicle	Supplementary
PhD	P. Toniato, UQ	Mach 12 Scramjet testing in X3 expansion tube	Supplementary
PhD	S. Stennett, UQ	Flow Condition Optimisation and Characterisation for a New Large Scale Reflected Shock Tunnel	Supplementary
PhD	T. Cullen, UQ	Re-entry Shock Layer Thermography	Supplementary
PhD	S. Francis, ANU	A Robust Laser Interferometer for Multiplexed Measurements of Optical Path Lengths	Supplementary
PhD	Y. Zhao, RMIT	Two-line element data quality control and its application in Space Situational Awareness	Supplementary
PhD	S. Raj, ANU	Space Debris Tracking using Continuous Wave Laser	Supplementary
PhD	E. Thorn, ANU	Design of SERC Adaptive Optics Laser Guide Star Facility	Supplementary
PhD	A. Zovaro, ANU	Adaptive Optics for Space Debris Manoeuvring and Astronomy	Supplementary
PhD	M. Copeland, ANU	Advanced Imaging and Wavefront Sensing for Satellite Laser Ranging and Tracking.	Supplementary
BSc & BEng R&D (Hons)	A. Stuchbery, ANU	Design, Construction & Testing of a Camera Latency Measurement Device	Undergraduate
PhD	J. Cranney, UoN	Predictive control of adaptive optics systems for observations and tracking of space objects and debris	Supplementary
PhD	L. Roberts, ANU	Development of a high-power optical phased array for space debris tracking and manoeuvring	Supplementary
PhD	A. Bah, UTS	Reconfigurable Ultrawide Band Tightly Coupled Arrays	Supplementary
PhD	H. Cai, RMIT	Space Debris Risk Assessment System Design	Supp FY 16/17
PhD	A. Harris, RMIT	Short Arc Orbit Determination	Supp FY 16/17
PhD	A. Yeasmin, RMIT	Monitoring, Mapping and Modelling Atmospheric Density Using the Swarm Mission	Supp FY 16/17
Undergrad	R. Murray, ANU	Laser beam centring strategies for the Laser Launch Telescope.	AITC
Undergrad	T. Dixon, ANU	Conceptual analysis of a camera latency measurement gig	AITC

Table 01: Students involved with SERC research. Supplementary and Undergraduate Scholarships. Supp FY16/17 = Supplementary Scholarship in financial year 2016/2017; AITC = This was an AITC summer student program (8 weeks over November 2015 to January 2016).

2.0 RESEARCH

2.5 SME ENGAGEMENT

Whilst Australia is home to some of the best space technologists in the world, the high entry costs and investment required to participate in the space industry in the past means there are a limited number of space SMEs currently operating in Australia. This is changing rapidly, however, with the reduced costs of access to space offered by new technology such as cubesats.

SME representation in the Australian space industry is largely comprised of technology companies and space industry service providers who offer support and technology to the larger players, primarily owners and operators of space-based infrastructure. This highlights the importance of SERC engaging with and supporting SMEs to build critical mass and a sustainable space industry in Australia.

During the 2015/16 reporting period, SERC General Manager presented a paper at the Australasia Satellite Forum 2016. This forum is attended by SMEs and multinationals and is the major space-based infrastructure conference in Australia. Attendance at this event enabled SERC to initiate dialogue with potential SME contributors and to identify potential opportunities for SME engagement.

The broader market segment comprising companies who provide goods or services which rely on data afforded through satellite technology, has a much greater SME representation in Australia. While SERC has not been in a position to engage with these SMEs to date, strategies to increase this engagement will occur as SERC transitions toward commercialisation.

SMEs are represented at a number of levels within the SERC organisational structure, including:

- **SME Participants:** EOSSS is an SME Participant and represents the interests of SMEs within SERC. Prof.



Figure 05: EOS Space Research Centre at Mt Stromlo Observatory [large dome], used for SERC research activities.

Craig Smith is the CEO and Technical Director of EOSSS and the leader for RP1. Through leading the RP1 research team, Prof. Smith ensures that SME interests are considered through the delivery of SERC research outputs.

- **Board Representation:** Independent Board Member, Mr Brett Biddington is an SME business owner, ensuring that SME interests and perspectives are considered at a Board level.
- **Research Management Committee Representation:** SME interests are represented at the Research Management Committee level through EOS Group CEO, Dr Ben Greene, and EOSSS CEO, Prof. Craig Smith, Mr Rod Drury from LM and Mr Andrew Edwards from Optus further represent Industry and end-user perspectives.
- **Communications Strategy:** The SERC Communications Strategy identifies SMEs as key stakeholders and outlines strategies for communicating and engaging with SMEs within Australia and overseas.



3.0 **RESULTS**

3.0 RESULTS

3.1 UTILISATION & COMMERCIALISATION

The Space Environment Research Centre (SERC) achieved its utilisation milestones for 2015/16 through regular meetings with Participants and end-users, technical and design meetings and the delivery of two Research Colloquia. In addition, SERC is tracking well towards the delivery of a major international conference in 2018 to promote SERC research and commercialisation outcomes to a broad international audience.

Regular meetings with Participants

SERC CEO, Dr Ben Greene, met with senior representatives from each Participant organisation during the 2015/16 reporting period to ensure that Participant and end-user needs are being met.

In addition, SERC General Manager, Dr Steve Gower, regularly attended research and technical meetings to ensure that the research is tracking well against milestones.

Regular design and technical meetings were also held at the Research Program (RP) level. This culminated in full attendance at the SERC Colloquia where preliminary design review meetings were held for each RP.

SERC Research Colloquia

SERC held two Research Colloquia during the 2015/16 reporting period. Research Colloquia allow Participants to gain a deeper appreciation of the depth and

breadth of the research
across the four RPs
and a better



understanding of end-user requirements. The SERC Research Colloquia has also been successful in identifying areas for further collaboration between Participant organisations and end-users.

Preliminary Design meetings

Technical meetings were held throughout the year for each RP. This activity culminated in preliminary design meetings being held in conjunction with the SERC Research Colloquium in May 2016. Research Management Committee member, Prof. Moriba Jah, participated in the technical review meetings and provided valuable input into this process.

Participation in colloquia sessions prior to the design and review meetings enabled Participants to contemplate the contribution of their own research to the greater research plan prior to in depth technical discussions.

Industry Liaison

SERC has increased its profile and gained a better appreciation of non-Participant end-user requirements through participation at national and international conferences. During the 2015/16 reporting period, SERC representatives delivered papers and attended national and international space industry conferences and workshops including the Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS), the International Workshop on Laser Ranging (IWLR), the Australasia Satellite Forum and the American Institute of Aeronautics and Astronautics (AIAA) conference.

International Workshop on Laser Ranging

Figure 06: Dinner conversation at the 2016 Research Colloquium, Dr Fumihiko Tomita, Vice President, NICT (left) and Dr Ben Greene, Chief Executive Officer, SERC (right).

3.0 RESULTS

3.1 UTILISATION & COMMERCIALISATION

– 2018

During the reporting period, SERC launched a successful bid to host the 20th IWLR in Canberra in 2018. The IWLR is a five-day international workshop devoted to laser ranging and is regarded as the world's leading workshop in this field. The workshop is attended by delegates from international space agencies, space research centres and universities including (but not limited to) the National Aeronautics

and Space Administration (NASA), the Smithsonian Astrophysical Observatory, German Research Centre for Geosciences, Japan Space Agency (JAXA) and the European Space Agency (ESA). Hosting the IWLR will provide an unprecedented opportunity to communicate SERC research success to end-users and the international space debris tracking and laser ranging community.

3.0 RESULTS

3.2 INTELLECTUAL PROPERTY MANAGEMENT

SERC employs industry best practice in the management of Intellectual Property (IP) as detailed in the *National Principles of Intellectual Property Management for Publicly Funded Research*. In support of IP management, SERC:

- Adheres to the *Australian Code for the Responsible Conduct of Research*.
- Has clear policies and procedures in relation to the ownership and associated rights for all IP generated through Centre activities (Centre IP).
- Has clear policies relating to the exploitation of IP generated through Centre activities.
- Makes all Centre IPs openly accessible through licencing arrangements which provide exclusive opportunities to undertake commercial exploitation.
- Provides support to researchers in identifying, developing and protecting Centre IPs whilst

upholding the academic requirement to publish.

- Provides guidance in relation to potential conflicts concerning IP management, ownership, promotion, dissemination, exploitation and, where appropriate, protection of IP.
- Provides guidance on the licensing of copyright, in particular, the criteria for publishing under the terms of open access licences.

The SERC *Intellectual Property Confidentiality and Disclosure Policy* was approved by the SERC governing Board during the reporting period. This Policy makes clear to all staff their responsibilities in relation to IP management including, where appropriate, the maintenance of research records (including lab books where possible, and field notebooks) and the handling of research results prior to promoting and disseminating the IP or obtaining IP protection.

3.0 RESULTS

3.2 INTELLECTUAL PROPERTY MANAGEMENT

IP Awareness and Training

To build awareness of the importance of IP amongst researchers, SERC has implemented a number of initiatives:

1. Numbered lab notebooks have been issued to all SERC researchers and students.
2. Prior to publication approval being given, all publications and presentations are vetted by SERC for unintentional disclosure of Centre IP.
3. Participant Quarterly Reports have a section relating to IP. Information disclosed in these reports are used to populate a comprehensive register of both Participant background IP and Centre IP developed during the quarter.
4. An *Intellectual Property Identification and Protection Workshop* was delivered to all SERC

Participant researchers and students as part of the May 2016 Research Colloquium. This workshop was given by Dr Justin Coombs, a registered patent attorney and General Manager of the Cell Therapies CRC. The workshop presented the core concepts of intellectual property (IP) including disclosure, novelty, inventive step and utility. Researchers were given real world examples to introduce the different types of intellectual property and show people how to identify it in a product. Dr Coombs highlighted what to look for in a patent specification, including practical advice on claims drafting; the practical aspects of background IP; Centre IP; and how each relates to commercialisation of SERC Research.

No registered IP was sold, transferred or licensed for commercialisation during the reporting period.

3.0 RESULTS

3.3 COMMUNICATIONS

SERC communication activities during the 2015/16 reporting period have focussed on strengthening internal communication to effectively support and promote Participant collaboration, build brand recognition and establish credibility in the international space science community.

In addition, the SERC Communications Strategy was reviewed and updated in line with Commonwealth annual reporting requirements.

Internal Communications

Internal communication and Participant relationship management is of paramount importance to SERC. Internal communication activities during the reporting period include:

Regular meetings with Participants: Regular meetings and communication is encouraged within SERC to ensure all aspects of the CRC are running as efficiently as possible. This is especially important with Participants who are not located in the same physical location.

3.0 RESULTS

3.3 COMMUNICATIONS

Research Colloquia: Are an important ‘whole of organisation’ communication method and an essential component of the SERC internal communications strategy.

Quarterly and Annual reports: Participants compile reports on their progress against milestones which is reported back to SERC corporate on a quarterly basis, this information is reported to stakeholders, including the Commonwealth.

SERC Newsletter: The SERC newsletter *SERCular* was launched during the reporting period. This newsletter is distributed regularly to Participants to communicate successes and foster collaboration. Researcher profiles and information on SERC upcoming events and activities are included to connect researchers and build a sense of community.



Figure 07: SERCular quarterly newsletter example.

External Communications

During the 2015/16 reporting period, SERC has built on the external communication efforts during the establishment year to build international brand

awareness and credibility in space science and laser ranging fields. External communication activities during the reporting period include:

Attendance at International Conferences and Workshops

SERC researchers and students have been invited to present at a total of eight international conferences in 2015/16. All presentations are pre-approved by SERC to ensure that a high standard is met and that no IP is inadvertently released.

Publications

Through publication in quality scientific journals, SERC is building credibility and brand awareness within the space sciences community. All researchers are encouraged to publish in top level peer-reviewed journals.

Press and radio coverage: SERC issued a number of press releases throughout the year, resulting in significant media coverage including:

- three live television interviews including a feature story on the ABC nightly news;
- five radio interviews including ABC Radio, Radio National and Radio ECU (Perth); and
- seven newspaper/web stories about SERC activities including articles in *The Age*, *Sydney Morning Herald*, *Brisbane Times* and *Aviation Business*.



Figure 08: TV interview given by Prof. Jah, Member of the SERC Research Management Committee.

3.0 RESULTS

3.3 COMMUNICATIONS

Website: The SERC website has continued to develop content, informing Participants, industry, students, and the public regarding SERC news and objectives. This reporting period has seen the depth of content increased, building data around SERC events and media coverage.

Social media: The SERC Facebook page (www.facebook.com/serc.aus) continued to gain momentum throughout the reporting period. Posts have highlighted SERC events and stories of interest were generated across a variety of space debris specific and related stories. On average SERC has been posting or reposting three stories each week, maintaining an active profile across our following.

SERC has established accounts on both LinkedIn and Twitter and will be looking to extend their use and following in the coming period.

Community outreach: SERC has expanded its reach into the community through selective sponsorship of events, some crossing over into our education objectives. The STEM X Academy in 2016 included presenters from various research schools, SERC and our industry partner EOSSS. Evidence that the issue of space debris and space environment management is beginning to be introduced into the classroom has been received, with one school performing a follow up interview with Dr Ben Greene to learn more about these important issues.

On the 21st August 2015, SERC sponsored the successful World Record Stargazing event. Two Guinness World Records were set: 1) Most People Stargazing from a Single Site (1,869 people at SERC Participant ANU's campus in Canberra); 2) Most People Stargazing across Multiple Sites in a Country, with 7,960 people across 37 sites in Australia participating

in the event. SERC's logo was included on the box of the commemorative telescopes provided to attendees.



SERC 4.0 RESOURCES

4.0 RESOURCES

4.1 GOVERNANCE – BOARD, COMMITTEES & KEY STAFF

The Space Environment Research Centre (SERC) is an Australian Public Company, Limited by Guarantee. SERC has been endorsed by the Australian Tax Office as a registered charity, effective 10 April 2014. SERC is exempt from income tax under Subdivision 50-A of the *Income Tax Assessment Act 1997*.

SERC's Strategic Plan, adopted on 18 March 2015, outlines the mission, vision, core values and strategic objectives for SERC. The Strategic Objectives for the initial three-year period are:

- Identify and exploit synergies between the research efforts of initial Participants so that the research objectives are collectively more advanced than would have been the case without SERC; and
- Establish efficient, equitable and transparent processes for combining resources from a wide range of collaborating entities.

Over this reporting period, SERC has built on the strategic objectives achieved during its initial year. SERC has strengthened its corporate governance and leadership at both the Board and Committee level.

The SERC Board of Directors was originally established on 10 April 2014, with three Independent Directors. Subsequently, a Director nominated by research Participants and a Director nominated by industry Participants were elected to the Board on 18 November 2014. The former resigned the position to take up a role as a member of SERC Management on 24 December 2016 and a replacement Director was appointed on 11 December 2015.

The Board governs SERC through specific policies and guidance to management in accordance with the constitution and in compliance with all applicable statutes. The SERC Board has adopted and operates within the CRC Programme Principles for CRC Governance.

The Board delegates to committees and management in accordance with the SERC *Delegations of Authority Policy*, which was adopted in March 2015.

Figure 09: View from the EOS Space Research Centre, Mount Stromlo Observatory, Canberra.



SERC Board



**Prof. Mary O'Kane AC,
Chair, SERC Board**

Professor Mary O'Kane is Principal of O'Kane Associates, a Sydney-based company specialising in major government and research reviews.

She is also the New South Wales Chief Scientist & Engineer and a company director, being Chair of the Development Gateway and the Development Gateway International, Chair of the Cooperative Research Centre for Spatial Information, Chair of the University of Tasmania Institute of Marine and Antarctic Studies Board, Director of Business Events Sydney, the Capital Markets CRC, and the Innovative Manufacturing CRC. She is also a trustee of the New Zealand Antarctic Research Institute.

She was Vice-Chancellor of the University of Adelaide from 1996 to 2001. She was formerly Chair of the Australian Centre for Renewable Energy and is a former member of the Australian Research Council, the CRC Committee, the Tax Concession Committee, the board of the CSIRO, and the board of F.H. Faulding & Co Ltd. She is a Fellow of the Academy of Technological Sciences and Engineering and an honorary Fellow of Engineers Australia.

With a prolific career in science spanning several decades, Emeritus Professor Mary O'Kane has been recognised for her contributions as one of the Australia's leading scientific experts and consultants.

Both a speech-recognition technology pioneer and chief government consultant, Professor O'Kane was made a companion of the Order of Australia for her eminent service to the field.



**Mr Brett Biddington AM,
Director (Independent)**

Mr Brett Biddington runs his own Canberra-based consulting firm, focusing on space and cyber-space policy, security and industry development subjects.

He was a member of the Government's Australian Space Industry Innovation Council, Chair of the Space Industry Association of Australia and is also involved with the governance of Australian astronomy. Mr Biddington has written two papers for a Canberra-based 'think-tank' (www.kokodafoundation.org) that discusses some of the factors Australia needs to consider as it develops its national space policy and capabilities.

Between 2002 and 2009 Mr Biddington was a member of the Global Space Team of Cisco Systems. This followed a 23 year career in the Royal Australian Air Force where he specialised in intelligence, security and capability development. Mr Biddington sponsored a wide range of command and control, intelligence, surveillance and reconnaissance projects, including the Jindalee Over the Horizon Radar Project (JORN) and classified space projects.



**Ms Elizabeth Whitelaw,
Director (Independent)**

Ms Elizabeth Whitelaw is a former senior partner of law firm Minter Ellison. She is a Member of the Australian Institute of Company Directors and is an experienced board member, having performed both Chair and non-executive Director roles for government-owned corporations, partnership boards, advisory bodies and not-for-profit organisations.

Ms Whitelaw was a member Minter Ellison's National Partnership Board, Canberra, Chair of Partners, a National Government Industry group leader and leader of the Canberra Infrastructure and Finance team. Ms Whitelaw was also Minter Ellison's board representative on the National Risk Assessment and Management Committee.

SERC Board



**Mr Rod Drury, CSC,
Director (Industry Partner)**

Mr Rod Drury is the Director – International Strategy and Business Development for Lockheed Martin’s Space Systems Company. In this role he is responsible for the growth of Space System’s portfolio of products and services across Australia and Asia.

Mr Drury has significant experience in the global aerospace sector, where he has carried out a variety of roles covering strategy, governance, business development, government and international relations, program management and research and development.

Mr Drury is a member of the Executive Committee of the Space Industry Association of Australia. In addition, he is an active company owner/operator with a focus on commercial activities within the Australasian region.



**Prof Matthew Colless,
Director (Research Partner)**

Professor Matthew Colless is Director of the Research School of Astronomy and Astrophysics at the Australian National University (ANU). He was, for nine years previously, the Director of the Australian Astronomical Observatory (AAO). He obtained his BSc at Sydney, his PhD at Cambridge, and has held positions at Durham, Kitt Peak and Cambridge and at AAO and ANU.

Professor Colless is a Fellow of the Australian Academy of Science, an Honorary Fellow of the Royal Astronomical Society, an ISI Citation Laureate, a former Vice-President of the International Astronomical Union and the ANU’s Founder representative for the Giant Magellan Telescope (GMT) project. He is also a member of the Visiting Committee or Science Advisory Board for the Leibniz Institute for Astrophysics at Potsdam, the Max Planck Institute for Extraterrestrial Physics at Garching and the European Southern Observatory.



**Dr Steve Gower,
Director (Research Partner)**

Dr Steve Gower was recently Director – Research Collaborations and Partnerships at RMIT University and responsible for liaisons with key stakeholders, including state and federal governments, industry, universities, CRCs and research organisations, both domestic and international.

Dr Gower was responsible for the establishment of international research laboratories, research contracts, intellectual property and commercialisation; and has served on many boards and committees. He resigned his position with the SERC Board to take up the role of SERC General Manager in January 2016.

4.0 RESOURCES

4.1 GOVERNANCE – BOARD, COMMITTEES & KEY STAFF

Board Attendance:

The Board of Directors met five times during the 2015 - 2016 reporting period, with meetings held on the following dates:

2015: 19 August, 9 October, 18 November

2016: 19 February, 15 April

The Public Officer during the reporting period was Ms Jaye Martin, Company Secretary.

Director	Attendance	
	Eligible	Attended
Prof. Mary O’Kane	5	5
Mr Brett Biddington	5	4
Ms Elizabeth Whitelaw	5	5
Dr Steve Gower	3	3
Mr Rod Drury	5	5
Prof. Matthew Colless	2	2

Table 02: Board Member attendance at SERC Board meetings for 2015/16.

The SERC Board is advised by various Board Committees. In April 2016, the Board resolved to merge the Audit and Risk Management Committees.

Audit Committee

The principal function of the Audit Committee is to ensure that appropriate controls and processes are in place to identify all risks relating to financial reporting and that these risks are being effectively monitored and managed. The Committee also reviews accounting policies affecting SERC and ensures disclosure in the financial statements of the CRC. The Audit Committee meets as needed throughout each year.

Synergy (formerly Moore Stephens) was appointed in 2015 as the independent auditor. During the reporting period, the Audit Committee also sought expert advice from RSM Bird Cameron as required.

Ms Jane Tisdall, Financial Controller, Defence Materials Technology Centre (DMTC) was appointed as Advisor to the Audit Committee, effective September 2015. Ms Tisdall is a member of CPA Australia and the Taxation Institute of Australia.

Contracts and Licences Committee

This committee met three times during the reporting period and assists the SERC Board in identifying

and investigating potential conflicts of interest. A monthly report outlining any contract or expenditure cumulatively over \$10,000 (with any supplier, over a rolling 12-month period) is compiled, checked against the conflicts of interest register and then submitted to the Contracts and Licences Committee for review.

Nominations and Remuneration Committee

The Nominations and Remuneration Committee meets as required. At least one meeting a year is used to assist the Board in fulfilling its corporate governance responsibilities with regard to the selection and appointment of Board Directors; and review of CEO and SERC Management Team performance. The Nominations and Remuneration Committee met once during this reporting period.

Risk Management Committee

The Risk Management Committee meets as required to identify, monitor and advise the Board and Executive on potential, perceived and actual risks to the CRC. A risk register has been developed and is reviewed at least quarterly to monitor and implement risk mitigation strategies. Risks that are considered to have a high impact on, or pose a high risk to, the CRC are brought to the prompt attention of the Board.

4.0 RESOURCES

4.1 GOVERNANCE – BOARD, COMMITTEES & KEY STAFF

Audit and Risk Management Committee

In April 2016, the Board resolved to combine the functions of the Audit Committee and the Risk Management Committee. The Audit and Risk Management Committee is scheduled to meet for the first time early in the next reporting period.

Research Management Committee

The Research Management Committee meets as required, but up to four times a year. This committee has been established under the constitution to (inter alia) advise the Board on decisions relating to the Research Programs (RPs), including setting research priorities, identifying education and student development opportunities and providing quarterly recommendations to the Board.

The Committee provides expert advice to SERC on the scope and effectiveness of the research activities; whether the program is on target to meet the research objectives; and assists in the review and identification of worldwide developments in relation to space technologies and space debris mitigation.

The Research Management Committee is specifically charged to:

1. evaluate the merits of proposed research;
2. advise the Board on the conduct and nature of research undertaken by SERC;
3. ensure the research undertaken is scientific in nature and is, or may prove to be, of value to Australia; and
4. administer the SERC Research Fund, determining how funds held are applied to research purposes.

Figure 10: SERC is located in The ANU Advanced Instrumentation Technology Centre (AITC) at Mount Stromlo Observatory, a world-class facility for developing and testing astronomical instrumentation, small satellites, and space payloads.

The Committee has representation from international research Participants, end-user Participants, SME Participants and independent researchers with specialist domain knowledge. Prof. Elaine Sadler was appointed in February 2016, and is the second independent expert to join the Research Management Committee. SERC is currently recruiting additional independent members to augment the considerable skills and expertise already available to SERC and to establish an independent majority on this important committee.

During this reporting period, Research Management Committee members attended the November 2015 and May 2016 Research Colloquia. This provided Committee members with an opportunity to assess the progress of each research program, attend technical research meetings and interact with researchers and students. Face-to-face Research Management Committee meetings were held in conjunction with the Colloquia to review the research programs and provide recommendations to management and the Board.



SERC Board Committee Meetings

Attendance at 2015-2016 Board Committee Meetings

Committee Member	Audit		Contracts & Licences		Nominations & Remuneration		Risk Management		Research Management	
	A	B	A	B	A	B	A	B	A	B
Prof. Mary O’Kane			3	3						
Mr Brett Biddington	1	1	3	3						
Ms Elizabeth White-law			3	3			1	1		
Dr Steve Gower	1	1								
Mr Rod Drury	1	1					1	1	2	1
Dr Ben Greene							1	1	2	2
Prof. Moriba Jah									2	2
Dr Fumihiko Tomita									2	2
Prof. Craig Smith									2	2
Mr Andrew Edwards									2	2
Ms Elaine Sadler									1	1

Table 03: Attendance at 2015/16 Board Committee Meetings. A = Number of meetings held during the time the Committee Member held office, B = Number of meetings attended.

SERC Research Management Committee Members



Dr. Ben Greene, Chair
Chair of the Research Management Committee

Dr Ben Greene is the Group CEO of Electro Optic Systems (EOS) and the CEO of SERC.

Dr Greene is internationally recognised for his expertise in space research and the development and commercialisation of innovative solutions in the tracking, monitoring and management of space debris. He is also the author of numerous patents and the architect and designer of a number of international space tracking systems.

Prof. Moriba Jah, Independent
Independent member of Research Management Committee
Director, Space Object Behavioral Sciences, UoA, USA

Prof. Moriba Jah received his BSc in Aerospace Engineering from Embry-Riddle Aeronautical University, Prescott, Arizona, and his MSc and PhD in Aerospace Engineering Sciences from the University of Colorado specializing in astrodynamics and statistical orbit determination.

While working at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, USA, he was a spacecraft navigator and also the principal investigator of a new approach to determine the position and velocity states of aerobraking spacecraft via the unscented Kalman filtering of inertial measurement unit data. Prof. Jah is a world-recognised subject matter expert in astrodynamics-based Space Situational Awareness sciences and technologies.



Prof. Elaine Sadler
Independent member of Research Management Committee
Director, Centre of Excellence for All sky Astrophysics (CAASTRO)

Elaine Sadler is Professor of Astrophysics in the School of Physics at The University of Sydney, and Director of the Australian Research Council Centre of Excellence for All-sky Astrophysics (CAASTRO).

Prof. Sadler's research focuses on galaxy evolution and aims to understand how galaxies form and change over billions of years of cosmic time. Much of her research involves the analysis of data from large-area optical and radio surveys of the sky. She has designed and undertaken several major astronomical surveys over the years, and currently leads the ASKAP-FLASH project. This project is using the new Australian SKA Pathfinder (ASKAP) telescope in Western Australia to learn about the amount and distribution of neutral hydrogen gas in very distant galaxies.

Prof. Sadler was elected a Fellow of the Australian Academy of Science in 2010. She has served as President of Division VIII (Galaxies and the Universe) of the International Astronomical Union (2009-2012) and Chair of the National Committee for Astronomy (2010-2012). As CAASTRO Director, Prof. Sadler oversees a 140-strong team of scientists and research students across seven Australian university nodes and 11 partner institutions around the world.



SERC Research Management Committee Members



Dr Fumihiko Tomita
Member of Research Management Committee
Vice President NICT, Japan

Dr Fumihiko Tomita is responsible for research strategy at the National Institute of Information and Communications Technology (NICT) Japan, and also for the leadership of future inter-industry ICT innovation projects in the Telecommunication Technology Committee (TTC), Japan. He was awarded a BSc degree in physics and MSc and PhD degrees in geophysics from the Tohoku University of Japan. After an appointment as Assistant Professor, Dr Fumihiko joined the Radio Research Laboratory (RRL) which later became NICT. He has been supervising various research strategies and programs in NICT, and is currently the Chief Research and Strategy Officer and Vice President of NICT.

Mr Rod Drury
Member of Research Management Committee
Regional Director – Australia, New Zealand & Asia Space
Systems Company International, Lockheed Martin (LM)

Mr Rod Drury has extensive director, consulting and executive experience in the space and security industries. Mr Drury is currently responsible for strategy and business development in Australia and Asia for LM. He is also a member of the Executive council of the Space Industry Association of Australia.



Prof. Craig Smith
Member of Research Management Committee
CEO and Technical Director, EOS Space Systems (EOSSS)

Professor Craig Smith is the CEO and Technical Director for EOS Space Systems. He leads a multi-disciplinary team of science and engineering innovators developing lasers, beam directors, precision timing systems, sensors, and control systems for the laser tracking products. Professor Smith has also held positions within Electro Optic Systems (EOS) as CEO of EOS Technologies (the US subsidiary of EOS) and Head of Research and Development.

Mr Andrew Edwards
Member of Research Management Committee
Manager, Satellite Support, Optus Satellite Systems (Optus)

Mr Andrew Edwards has over 30 years' experience in Satellite Operations and Orbit Dynamics. He is currently manager of the team which is responsible for the spacecraft engineering, orbit dynamics and computer equipment for current and future Optus operated spacecraft.

Andrew has supported mission analysis, station keeping, propulsion subsystem and fuel life estimation for all five generations of Optus's spacecraft.



4.0 RESOURCES

4.1 GOVERNANCE – BOARD, COMMITTEES & KEY STAFF

SERC Management Team

SERC management comprises an Executive and support staff as well as Research Program Leaders for each of the SERC Research Programs. Figure 11 shows the organisational structure of SERC. Table 04 shows the names and time commitments of key staff, including the Chief Executive Officer and Research Program Leaders .

SERC ORGANISATION CHART AS AT JUNE 30 2016

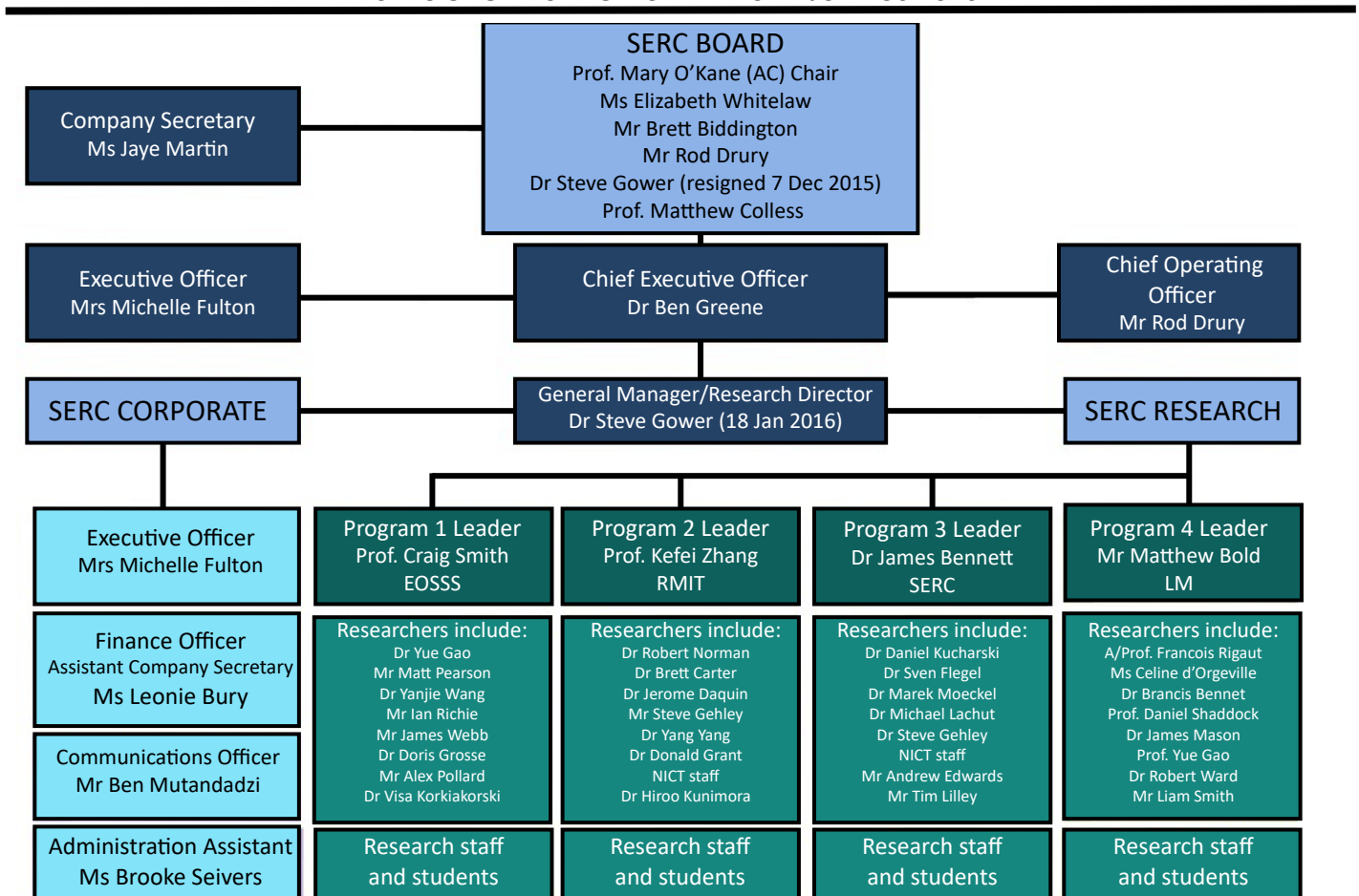


Figure 11: SERC Organisational Structure as at 30 June 2016.

4.0 RESOURCES

4.1 GOVERNANCE – BOARD, COMMITTEES & KEY STAFF

Name	Organisation	Role	FTE
Dr Ben Greene	Electro Optic Systems	Chief Executive Officer	75%
Dr Steve Gower	SERC		100%
Ms Michelle Fulton	Electro Optic Systems	Executive Officer	80%
Ms Sarah Burns	SERC	Executive Officer from May 2016	100%
Ms Leonie Bury	SERC	Finance Officer	80%
Dr James Bennett	SERC	Research Project Leader – RP3	100%
Mr Rod Drury	Lockheed Martin	Chief Operating Officer	10%
Prof Craig Smith	EOS Space Systems	Research Project Leader – RP1	52%
Prof Kefei Zhang	RMIT University	Research Program Leader – RP2	50%
Mr Matthew Bold	Lockheed Martin Space Systems	Research Program Leader-RP4	33%

Table 04: Names and time commitments of key staff for 2015/16. Dr Steve Gower was appointed General Manager in January 2016. Ms Sarah Burns replaced Michelle Fulton as Executive officer in May 2016.

4.0 RESOURCES

4.2 PARTICIPANTS

There were no changes to Essential or Other Participants during the reporting period. The Participants listed in the Commonwealth Agreement were the SERC Participants during the 2015/16 reporting period, including:

Essential Participants



EOS Space Systems ABN: 11 008 587 451

EOS is an Australian listed company, specialising in the design, development and production of satellite and space tracking technologies and the provision of space-based services. EOS's technologies are applied to a variety of sighting and surveillance applications in the aerospace and defence markets globally and have already generated over \$400m in exports for Australia. EOS has extensive optical tracking infrastructure uniquely suited to allow rapid on-orbit development and testing of space debris tracking and collision mitigation technologies.



RMIT University ABN: 49 781 030 03

The RMIT SPACE Research Centre is internationally recognised in the areas of astrodynamics, GPS tracking, atmosphere, space weather and ionospheric research. RMIT SPACE has considerable expertise in developing models for reliably propagating or forecasting orbits in the variable space environment. In a successful Australian Space Research Program (ASRP) collaboration, RMIT SPACE was instrumental in developing improved orbit determination algorithms, providing a platform for further SERC research.

**The Australian
National University**
ABN: 52 234 063 906



**Australian
National
University**

The ANU has demonstrated significant success in space science and engineering research and the development of end user applications. The Advanced Instrumentation and Technology Centre (AITC) at Mount Stromlo in Canberra is a \$30 million Federal Government investment in critical national infrastructure to support the design, manufacture, integration and testing of advanced space instrumentation and small satellites.



LOCKHEED MARTIN

Lockheed Martin (LMC) is one of the world's largest aerospace entities. It is both a potential user and a potential service provider for space environment management services. LMC space business exceeds \$8 billion annually. Notwithstanding this business scale, it regards space environment management as a growth sector and is investing in technology and market position through its Advanced Technology Centre. LMC brings a wealth of technology and research program performance experience to SERC, with in-depth skill sets and domain knowledge.

Other Participants



ABN: 15 091 789 945

Optus Satellite has been providing satellite services for over 30 years and is the only network provider in Australia to own and operate a fleet of satellites.

Since 1985, Optus has successfully launched ten satellites and operated thirteen spacecraft. The Optus Satellite fleet currently consists of six geostationary satellites providing satellite services across Australia and New Zealand, and to McMurdo Sound in the Antarctic.

Optus provides a significant proportion of Australia's telecommunications infrastructure through their fleet which has a commercial value exceeding \$8 billion and must be continually monitored for any increase in debris risk.



National Institute of Information and Communications Technology (NICT) Japan is charged with promoting the ICT sector as well as research and development in ICT, to drive economic growth and create an affluent, safe and secure society. NICT has a strong space mandate because ICT infrastructure is heavily dependent on space assets. In collaboration with Australia, NICT has built and deployed eight laser tracking systems throughout Japan over the past 20 years, and is a global leader in both optical space tracking and orbital science relating to high precision orbits. NICT operates major optical space tracking research laboratories and facilities which work collaboratively with SERC sites in Australia.

4.0 RESOURCES

4.2 PARTNERS

During the 2015/16 reporting period, SERC enhanced its international collaboration and reach through the signing of Memoranda of Understanding (MOU) with the University of Arizona, USA and the Space Research Institute in Graz, Austria.



The University of Arizona

SERC further strengthened its international collaboration efforts after signing an MOU with the University of Arizona (UA), USA.

UA's Space Object Behavioural Sciences (SOBS) mission is to assemble and lead the world's top multi-disciplinary science and technology research and development talent and focus it to solve problems requiring rigorous and comprehensive capabilities in assessing, quantifying, and predicting the behaviour of objects in space, both man-made and natural. UA SOBS also aims to imagine, identify, develop and deliver new space object behaviour capabilities; make expertise on space object behaviour available to a variety of stakeholders including all branches of government, private industry, academia, and international entities; and help guarantee the University of Arizona's leadership in the area through education, excellence, innovation and practicality in space object behavioural sciences and related fields.

The MOU establishes a framework for scientific collaboration between the two organisations that will result in the combining of the organisations' research expertise to achieve scientific goals whilst developing common specialised knowledge and effective use of facilities.

The MOU also opens the door to the exchange of scientific personnel including students in addition to opportunities for joint research and development.

MOUs



The Space Research Institute in Graz

SERC signed a Memorandum of Understanding (MOU) with the Satellite Laser Ranging (SLR) Observatory of the Space Research Institute, Graz, Austria. The MOU signals a marked increase in collaboration efforts between our two organisations.

The Space Research Institute in Graz is one of the largest Institutes of the Austrian Academy of Sciences. The institute focuses on physics and exploration of the solar system, covering the whole chain of research needed in its fields: from developing and building instruments such as the SLR, to analysing and interpreting the data returned by these instruments, with support from theoretical studies.

SERC is excited to be engaging in closer collaboration with the Space Research Institute in Graz, Austria, combining northern and southern hemisphere data on laser and optical observations of space debris including high-area-to-mass ratio objects and defunct satellites, spin dynamics analysis of observed targets, and determination of space debris optical properties for characterisation purposes.

4.0 RESOURCES

4.3 COLLABORATION

Collaboration between Research Participants

SERC has partnered with world leading space debris management companies and research organisations with strong track records in scientific discovery and technology development. SERC Participants include SME and multinational corporations, universities and research institutions and end-users. The continued success of SERC is reliant on facilitating collaboration and sharing of risk between these Participant groups.

Strong collaboration across the research programs has continued throughout the 2015/16 reporting period. Research results and collaborations are reported more fully in 2.0 Research, however a few highlights:

Project: Communication with the Japanese Hyabusa2 Satellite

Collaborators: EOSSS, NICT and JAXA.

Results: This collaboration achieved spectacular results and set a new world record for the maximum distance over which optical communication has taken place. There was great satisfaction when Hayabusa2, at a distance of 6.7 million kilometres from Earth, relayed a signal to JAXA that photons from the Mount Stromlo laser had been received by Hyabusa2.

Project: Development of AO imaging for Space Debris

Collaborators: EOSSS, ANU

Results: ANU is a world leader in AO. ANU experts in AO are working with SERC researchers and EOSSS to develop AO imaging technology for space debris. EOSSS has already won international contracts for current (2014) technology exports and SERC technology may win further orders.

Project: Spin dynamics and behaviour of objects in space.

Collaborators: Optus and SERC.

Results: SERC researchers are collaborating with Optus to learn more about the behaviour of defunct or end-of-life satellites in graveyard orbits. This research is providing SERC researchers with a greater understanding of the spin dynamics and behaviour of space debris objects.

Project: Space catalogue development

Collaborators: EOSSS, ANU, LM

Results: ANU, LM and EOSSS are collaborating to develop a Space Situational Awareness database for better orbit prediction and collision avoidance of space debris.

SERC collaboration between research Participants, industry and end-users during the reporting period are provided in Table 05 below.

Research program	Collaboration participants	Sector(s)
Research Program 1	EOS Space Systems	Industry, SME, End-User and Research
	ANU	Research and Education
	LM	Industry, Multinational, International
Research Program 2	NICT	Research and Education
	RMIT University	Research, International, Government
Research Program 3	OPTUS Satellite Systems	Industry and End-User
	EOS Space Systems	Industry, SME, End-User and Research
Research Program 4	EOS Space Systems	Industry, SME, End-User and Research
	LM	Industry, Multinational, International
	ANU	Research and Education

Table 05: Collaboration between research Participants.

4.0 RESOURCES

4.3 COLLABORATION

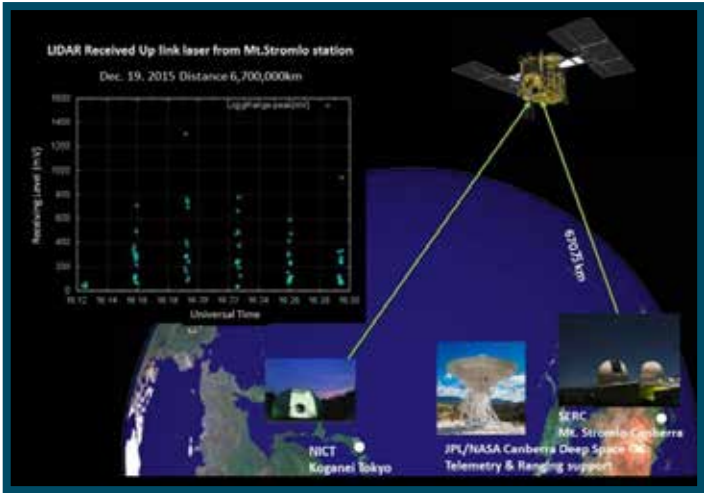


Figure 12: Japanese asteroid sample return mission satellite Hayabusa 2 relays a signal informing that it has received photons from SERC.

RP	Collaboration Participants
RP1	ANU (research)
	EOSSS (research and end-user)
	LM (research and end-user)
RP2	RMIT University (research)
	OPTUS Satellite Systems (end-user)
RP3	SERC (research)
	OPTUS Satellite Systems (end-user)
	EOSSS (research and end-user)
RP4	ANU (research)
	EOSSS (research and end-user)
	LM (research and end-user)

Table 06: Collaboration between research Participants and end-user Participants.

Research and end-user collaboration

Four of the six SERC Participants are potential end-users of SERC technologies and commercialised products and services. During the 2015/16 reporting period, significant collaboration and consultation was initiated between SERC Participants and end-users to ensure that end-user needs and requirements are met.

Collaboration between Participants and end-users occurred informally at the research level and formally through participation in SERC Colloquia, technical workshops, Research Program meetings and site visits.

An example of Participant and end-user collaboration is the consultation with Optus on conjunction analysis requirements and collision avoidance with accuracy enhancements currently being developed by SERC researchers.

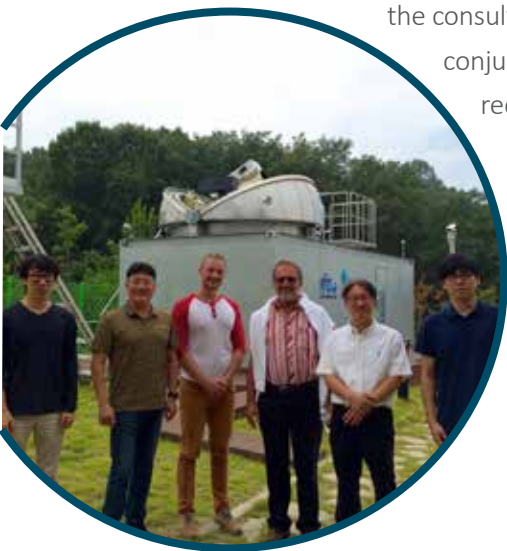


Figure 13: the KASI SLR team including Dr Georg Kirchner and Dr Hyiung-Chul Lim with SERC Researcher Daniel Kucharski at Sejong SLR Station.

External Linkages

Collaboration with external organisations was expanded during the 2015/16 reporting period. Research collaborations with the Graz Satellite Laser Ranging station which commenced in the 2014/15 reporting period were strengthened throughout 2015/16. The execution of a MoU with Graz facilitated enhanced collaborative research activities and researcher exchange with this leading European space research agency. Research activities focused on the measurement, analysis and modelling of spin dynamics of High Earth Orbit (HEO) space debris objects. Data from long term laser and optical observations of 40 defunct Global Navigation Satellite System (GNSS) satellites has been made available to SERC researchers to analyse the effects of solar radiation pressure on HEO objects. This research has the potential to improve the accuracy of orbit determination and prediction for telecommunication spacecraft and is of particular interest to SERC end-user Participant, Optus.

4.0 RESOURCES

4.3 COLLABORATION

New methods for light curve analysis are being developed in collaboration with the Graz SLR station. Three-dimensional representations of single-photon light curves are being used to estimate the attitude of sunlit objects and identify their shape (Figure 14). This research will support the orbital analysis of space debris objects in Low Earth Orbits (LEO).

SERC researchers are collaborating with Graz and NICT on a laser tracking campaign of the defunct satellite OICETS. This campaign will commence on 1 September, 2016 and involve the global SLR stations affiliated with the International Laser Ranging Service (ILRS). The OICETS satellite occupies a crowded polar orbit (altitude of 610 km) and presents interesting spin dynamics which are influenced by the forces and torques from the gravity and magnetic fields of the Earth and solar radiation pressure. SERC researchers from RP3 will analyse the data from this SLR campaign to gain a better understanding of the interaction between the space environment and space debris objects in low polar orbits.

External collaboration and a researcher exchange was initiated with KASI during the 2015/16 reporting period. Further insights into understanding the effects of space weather on space debris objects has resulted from this activity. It is anticipated that this collaboration will be strengthened in the next reporting period when data from the two new KASI SLR systems and the optical tracking network will be made available to SERC by agreement with KASI.

Further expansion of external collaboration activities is planned in 2016/17. Initial discussions have commenced with researchers from the Borowiec SLR station and the Institute of Geodesy and Geoinformatics in Poland. Areas of mutual interest

include the analysis of orbital decay and re-entry predictions of space debris objects from LEOs. The potential area of collaboration includes the development of an attitude dependent atmospheric drag model to determine the orbit decay rate of free-falling objects in space.

SERC is also developing external linkages with non-Participant universities in Australia; sourcing the most promising students for scholarship opportunities. Currently this non-Participant university collaboration includes the University of Queensland, the University of Newcastle, the University of Technology, Sydney and the University of Sydney.

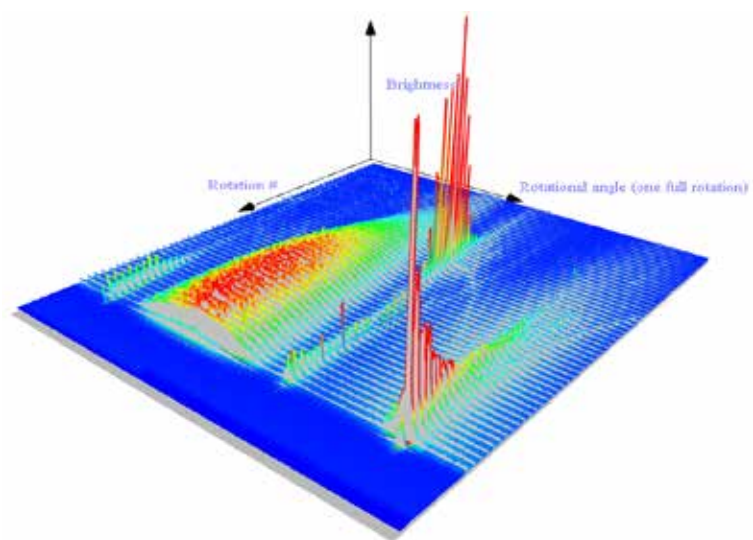


Figure 14: The 3-D light curve representation of defunct satellite Topex (altitude of 1300 km, measured in March 2016) allows to distinguish between the diffused and specular sunlight reflections from the s/c body.

4.0 RESOURCES

4.4 FINANCIAL MANAGEMENT

SERC continued to implement stringent financial management practices in an aggressive attempt to allow 70% of all cash funds to flow to the SERC research and education programs.

Although administrative costs were slightly higher this financial year, SERC managed to contain administrative costs to below the target 30% of budget.

SERC has continued to improve its financial processes throughout the reporting period, with a number of key achievements:

- Improved functionality and management of accounting and payroll processes
- Enhanced budgeting and forecasting process implemented
- Better financial reporting to the Board, Committees and research programs
- Adherence to stringent budgeting guidelines ensured SERC tracked well against budgets and maintained a strong cash-flow position
- Successful cost minimisation measures have enabled a new Space Segment Research Program to be funded within existing budgets

SERC financial management has continued to improve through a 360 degree review of financial management processes.

There were no significant issues with respect to financial management during the 2015/16 reporting period.

Funds Carried Forward

SERC carried \$5,127,773 forward at 30 June 2016. These funds are (largely) committed to the purchase of capital items and the new Space Segment RP which will commence in the next reporting period.

Administrative Costs

SERC recruited additional executive and administrative resources during the 2015/16 financial year which accounted for the slight increase in administrative expenditure. A General Manager was appointed in January 2016 and a Communications Officer in February 2016. SERC is now operating with a full complement of administrative resources to support the RPs.

Travel

SERC staff, students and Participants were invited to deliver papers at a number of key national and international conferences during the reporting period.

In addition, SERC Participants, students and members of the Research Management Committee travelled to Canberra for two research colloquia and a lecture series on Astrodynamics delivered by an international subject matter expert.

Key Changes from 2015

SERC has continued to track well against its aggressively lean cash flow projections. The key change in 2015/16 is the reallocation of reserves to fund a new Space Segment Research Program including the proposed launch of satellites.

All SERC funds are now fully committed to 30 June 2019.

Participant Cash Contributions

During the reporting period, SERC received 100% of pledged cash contributions from Participants. Cash contributions were \$380,000 in line with Participant Agreements.

4.0 RESOURCES

4.4 FINANCIAL MANAGEMENT

Participant In-kind Contributions

SERC is required, under its constitution, to audit all Participant contributions claimed for both quantity (magnitude) and quality.

Aggregate in-kind contributions received from Participants were in excess of 95% of the pledged amounts during the 2015/16 reporting period.

SERC Participants contributed a total of 13.3 FTE compared to the pledge of 14.3 FTE. The staff in-kind contributions shortfall received from Participants was offset by non-staff in-kind contributions totalling \$3.5 million which was in excess of the \$3.2 million pledged..

Non-staff in-kind contributions received from Participants totalled \$3.5 million which was in excess of the \$3.2 million pledged.

Financial Statements

The Annual Financial Statements have been prepared as general purpose accounts in accordance with the Commonwealth Government reporting requirements for CRCs; and in-line with Australian Accounting Standards.



OTHER ACTIVITIES

5.0 OTHER ACTIVITIES

SERC has not undertaken any activities outside of Activities specified in the Commonwealth Agreement during the current reporting period.

A dramatic photograph of a Space Shuttle launching from the launch pad. The shuttle is ascending vertically, leaving a massive, billowing plume of white and orange smoke and fire. The launch pad structure, including service towers and railings, is visible in the foreground and midground. The sky is a pale, hazy blue.

SERC 6.0 ADDITIONAL REQUIREMENTS

6.0 ADDITIONAL REQUIREMENTS

6.1 EXTERNAL REVIEWS

SERC was advised that there would not be an external review by the Commonwealth during this reporting period.

6.2 INTERNAL REVIEWS

A full review of the SERC Research Programs was completed in June 2016. The review was conducted by the Research Management Committee and involved the four Research Program Leaders. The SERC Research Program review process is outlined in Figure 15.

The SERC Research Program Review generated a report which included recommendations to maintain, enhance, terminate and initiate various research efforts to optimise program outcomes and conserve resources. This report was submitted to the Commonwealth as part of a proposal to vary the Commonwealth Agreement in June 2016.

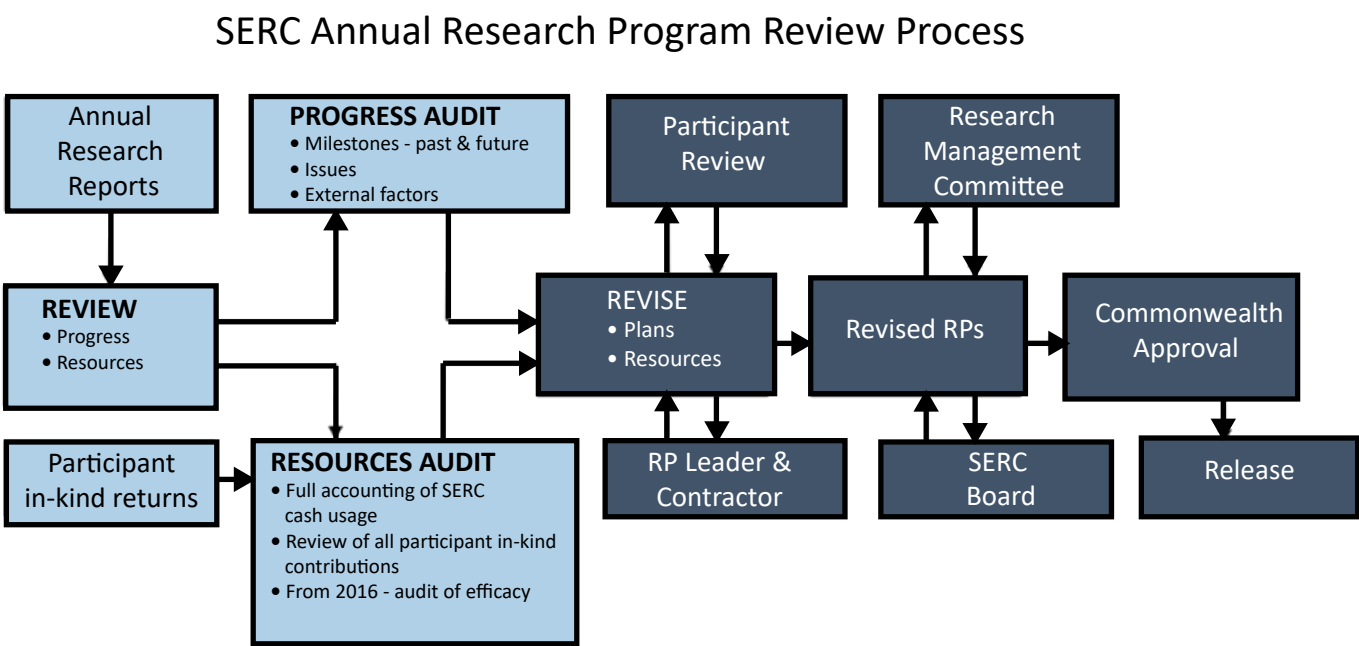


Figure 15: The SERC Annual Research Program Review Process.



SERC 7.0 GLOSSARY

7.0 GLOSSARY OF TERMS

Term	Definition
AAO	Australian Astronomical Observatory
AIAA	American Institute of Aeronautics and Astronautics
AITC	The ANU's Advanced Instrumentation and Technology Centre located at Mount Stromlo Observatory in Canberra, Australia.
AMD	Atmospheric Mass Density
AMOS	Advanced Maui Optical and Space Surveillance Technologies Conference
ANU	The Australian National University
AO	Adaptive Optics: a technology used to improve the performance of optical systems by reducing the effect of wavefront distortions. It aims at correcting the deformations of an incoming wavefront by deforming a mirror in order to compensate for the distortion.
AOTP	AO Tracking & Pushing
ARI	Approved Research Institute
ASKAP	Australian SKA Pathfinder
ASRP	Australian Space Research Program
CAASTRO	Australian Research Council Centre of Excellence for All-sky Astrophysics
CATW	Conjunctions Analysis and Threat Warning
CDR	Critical Design Review
Centre IP	Refers to the Intellectual Property held by SERC
CoDR	Conceptual Design Review
Colloquium	An academic conference or seminar
CRC	Cooperative Research Centre
DMTC	Defence Materials Technology Centre
EIPT	Economic Impact Performance Tool (round 11 onwards)
EOSSS	EOS Space Systems Pty Limited
ESA	European Space Agency
FBT	Fringe Benefits Tax
GEO	Geostationary earth orbit
GMT	Giant Magellan Telescope
GNSS signal paths	Refers to signal paths from the Global Navigation Satellite System, a constellation of satellites providing signals from space transmitting positioning and timing data.
GPS	Global Positioning System
GRACE	Refers to the Gravity Recovery and Climate Experiment (GRACE) twin satellites which measure the movement of mass, and hence gravity, around earth every 30 days.
Graz SLR	The Space Research Institute in Graz
GST	Goods and Services Tax
GUI	Graphical User Interface
HEO	High Earth Orbit

7.0 GLOSSARY OF TERMS

Term	Definition
HDR	Higher Degree by Research
ICT	Information Communication Technology
ILRS	International Laser Ranging Service
IP	Intellectual property
IR	Infrared
IWLR	International Workshop on Laser Ranging
JAXA	Japan Aerospace Exploration Agency
JORN	Jindalee Over the Horizon Radar Project
JPL	NASA's Jet Propulsion Laboratory
KASI	Korea Astronomy and Space Science Institute
LEO	Low Earth Orbits
LGS	Laser Guide Star
LIGO	Laser Interferometer Gravitational Wave Observatory
LM	Lockheed Martin, formally Lockheed Martin Space Systems Company
MOU	Memorandum of Understanding
NASA	National Aeronautics and Space Administration
NCA	National Capital Authority
NICT	The National Institute of Information and Communications Technology (Japan)
OPAL	(brand name)
Optus	OPTUS Satellite Systems
PCE	Polynomial Chaos Expansion
POD	Precision Orbit Determination
PDR	Preliminary Design Review
RMIT	Royal Melbourne Institute of Technology University
RO	Reliable Orbit
ROD	Reliable Orbit Determination
RP	Research Program
RRL	Radio Research Laboratory
RSAA	The Australian National University's Research School of Astronomy and Astrophysics.
SERC	Space Environment Research Centre
SLR	Satellite Laser Ranging
SME	Small to medium enterprise
SOC	Satellite Object Catalogue
SPACE	RMIT's Satellite Positioning for Atmosphere, Climate and Environment Research Centre
SPAN	RMIT's Satellite Positioning and Navigation Laboratory
SSA	Space Situational Awareness is the ability to accurately characterise the space environment and activities in space.

7.0 GLOSSARY OF TERMS

Term	Definition
STEM	Science, Technology, Engineering and Mathematics
STEM X	The Australian Science Teachers Association's Science, Technology, Engineering and Mathematics teacher development program.
TIRA	Tracking and Imaging Radar
TTC	Telecommunication Technology Committee
WFOV	Wide Field of View
WPLTN	Western Pacific Laser Tracking Network



APPENDICES

Appendix 1

2015 – 2016 Publications & Presentations

Formal publications

Date	Title	Published in/presented at:	Authors	Publication type
2015	Future Space Debris Tracking Requirements	33rd AIAA International Communications Satellite Systems Conference	C. Smith, B. Greene	Conference proceedings
2015	Interplanetary Shocks and the Resulting Geomagnetically Induced Currents at the Equator	<i>Geophysical Research Letters</i> ; 42 (16), pp. 6554-6559	B. A. Carter, R. Norman, K. Zhang	Journal article
2015	Australian Space Research Program – Platform Technologies for Space, Atmosphere and Climate Project: Selected Innovations	Applications + Practical Conceptualization + Mathematics = fruitful Innovation	R. Norman, B. Carter, J. Bennett, J. Le Marshall, J. Hearne, K. Zhang	Book chapter
2015	The challenge of precise orbit determination for STSAT-2C using extremely sparse SLR data	Advances in Space Research In press	Y. R. Kim, E. Park, D. Kucharski, H.C. Lim, B. Kim	Journal article
2015	Confirmation of gravitationally induced attitude drift of spinning satellite Ajisai with Graz high repetition rate SLR data	Advances in Space Research In press	D. Kucharski, G. Kirchner, T. Otsubo, H. C. Lim, J. Bennett, R. Koidl, Y. R. Kim, J. Y. Hwang	Journal article
2015	Orbit determination using SLR data for STSAT-2C: Short-arc analysis	<i>Journal of Astronomy and Space Science</i> ; 32, (3), 2015, Pages 189-200	Y. R. Kim, E. Park, D. Kucharski, H. C. Lim	Journal article
2015	Initial Overview of Satellite-ground Laser Communication Experiment using Small Optical Transponder (SOTA)	Institute of Electronics, Information and Communication Engineers of Japan Society, SAT2015-32(2015-16) pp.75-79	Y. Munemasa, H. Kunimori, M. Toyoshima	Journal
2015	Recent Activities on Space Laser Communications in Japan and First In-Orbit Verification for Micro-Satellites	Frontiers in Optics	M. Toyoshima	Proceedings

2015 – 2016

Publications & Presentations

Formal publications

Date	Title	Published in/presented at:	Authors	Publication type
2015	Spectrally resolved Hong-Ou-Mandel interference between independent photon sources	<i>Optics Express</i> 23 (22)	J. Ruibo, S. Miki	Journal
2016	Global equatorial plasma bubble occurrence during the 2015 St. Patrick's Day storm	<i>J. Geophys., Res.: Space Physics</i>	B. A. Carter, E. Yizengaw, R. Pradipta, J.M. Retterer, K. Groves, C. Valladares, R. Caton, C. Bridgwood, R. Norman, K. Zhang	Journal
2016	Interhemispheric Propagation and Interactions of Auroral Traveling Ionospheric Disturbances near the Equator	<i>J. Geophys., Res.: Space Physics</i>	R. Pradipta, C.E. Valladares, A. Carter, P.H. Doherty	Journal
2016	Lasers for Space Debris Relocation	OSA Laser Optics, St Petersburg, 2016	C. Smith, B. Greene	Conference Presentation
2016	High average power diode	OSA Laser Optics, St Petersburg, 2016	Y. Gao, Y. Wang, A. Chan, M. Dawson, B. Greene	Conference Presentation
2016	AO corrected satellite imaging from Mount Stromlo	SPIE conference on Astronomical Telescope and Instrumentation, Edinburgh	F. Bennet, F. Rigaut, I. Price, N. Herrald, I. Ritchie, C. Smith	Conference Presentation
2016	Single Detector stereo-SCIDAR for Mount Stromlo	SPIE conference on Astronomical Telescope and Instrumentation, Edinburgh	D. Grosse, F. Bennet, V. Korkiakoski, F. Rigaut, E. Thorn	Conference Presentation

Appendix 1

2015 – 2016 Publications & Presentations

Other publications and presentations

Date	Title	Published in/presented at:	Authors	Publication type
2015	Adaptive optics for satellite imaging and space debris ranging	Advanced Maui Optical and Space Surveillance Technologies Conference Maui Hawaii September 15 -18, 2015	F. Bennet, C.d'Orgeville, I.Price, F. Figaut, I. Ritchie, C. Smith	Conference proceedings
2015	Simpler Adaptive Optics using a Single Device for Processing and Control	Advanced Maui Optical and Space Surveillance Technologies Conference Maui Hawaii September 15 -18, 2015	A. Zovaro, F. Bennet	Conference proceedings
2015	From Dye Laser Factory to Portable Semiconductor Laser: Four Generations of Sodium Guide Star Lasers for Adaptive Optics in Astronomy and Space Situational Awareness	Advanced Maui Optical and Space Surveillance Technologies Conference Maui Hawaii September 15 -18, 2015	C. d'Orgeville	Conference proceedings
2015	Orbital element generation for an optical and laser tracking object catalogue	Advanced Maui Optical and Space Surveillance Technologies Conference Maui Hawaii September 15 -18, 2015	J. Bennett, C.Smith, B.Greene, D.Kucharski, F. Rigaut, F. Bennet	Conference proceedings
2015	AMOS SSA Policy Forum- Challenges and Opportunities from the Growing Private Sector Presence in Space	Advanced Maui Optical and Space Surveillance Technologies Conference Maui Hawaii September 15 -18, 2015	C. Smith	Presentation
2015	The Space Environment Management CRC	15 th Australian Space Research Conference	C. Smith	Presentation
2015	Integrated Photonic Devices for Quantum Key Distribution	5 th International Conference on Quantum Cryptography (Q Crypt 2015)	P. Sibson, S. Miki, T. Yamashita, M. Fujiwara	Proceedings

2015 – 2016

Publications & Presentations

Other publications and presentations

Date	Title	Published in/presented at:	Authors	Publication type
2015	Optical clock evaluation without a hydrogen maser by carrier-phase two-way satellite frequency transfer	2015 Joint Conference of the IEEE International Frequency Control Symposium & European Frequency and Time Forum	M. Fujieda, T. Gotoh	Proceedings
Sep-15	Report of the Environmental-data Statistical Processing for Satellite-to-Ground Stations Optical Communications	Institute of Electronics, Information and Communication Engineers of Japan (IECE) Society proceedings, SAT-No.B-3-9 pp.194	K. Suzuki, H. Kunimori, M. Toyoshima	Proceedings
2015	Recent Progress in Precise Orbit Determination of Communication and Broadcasting Satellites (in Japanese).	IEICE Technical Report, vol. 115, no. 180, SAT2015-17, pp. 35-39	T. Kubo-oka	Proceedings
2015	Flexible optical design and characterization of superconducting nanowire single-photon detectors with dielectric multilayer	Single Photon Workshop 2015	T. Yamashita, S. Miki, H. Terai	Proceedings
2015	Multi pixel superconducting single photon detectors with superconducting single flux quantum readout circuit	15 th International Superconductive Electronics Conference (ISEC 2015)	S. Miki, T. Yamashita, H. Terai	Proceedings
2015	Implementation of 1um SLR system in ground station for Optical Link experiment ranging to a deep space satellite.	The 37 th Seminar, Space Communication System, NICT,	H. Kunimori, T. Kubooka, T. Fuse	Presentation
2015	Space Debris Mitigation	3+ AIAA ICSSC 2015	A. Edwards, B. Greene, C. Smith, H. Kunimori	Panel Discussion
2015	On the vulnerability of the equatorial region to geomagnetically induced currents	Australian Space Research Conference	B. A. Carter, R. Norman, K. Zhang	Conference presentation
2015	The 2015 St. Patrick's Day superstorm: Effects in the near-Earth space environment and impacts on technologies	Australian Space Research Conference	B. A. Carter, R. Norman, K. Zhang	Conference presentation

2015 – 2016

Publications & Presentations

Other publications and presentations

Date	Title	Published in/presented at:	Authors	Publication type
2015	A method for Improving Two-line Element Outlier Detection Based on a Consistency Check	Advanced Maui Optical and Space Surveillance Technologies Conference Maui Hawaii September 15 -18, 2015	Y. Zhao, K. Zhang, J. Bennett, J. Sang, S. Wu	Conference presentation
2015	Space situational awareness- a new horizon of Australian space research	IGNSS conference	K. Zhang, J. Bennett, J. Sang, C. Smith, R. Norman, B. A. Carter, Y. Zhao, S. Wu	Conference presentation
2015	Space Situational Awareness (SSA) – the next serious challenge of space science and technology	Public seminar at JUST	K. Zhang	Public seminar
Aug-15	Damaging electric currents in space affect Earth's equatorial region, not just the poles	The Conversation	B. A. Carter	Online Science Media
2015	Orbital element generation for an optical and laser tracking object catalogue	Advanced Maui Optical and Space Surveillance Technologies Conference Maui Hawaii September 15 -18, 2015	J. Bennett, C. Smith, B. Greene, D. Kucharski, F. Rigaut, F. Bennet	Conference presentation
2015	Orbital element generation for an optical and laser tracking object catalogue	Advanced Maui Optical and Space Surveillance Technologies Conference Maui Hawaii September 15 -18, 2015	J. Bennett, C. Smith, B. Greene, D. Kucharski, F. Rigaut, F. Bennet	Conference proceedings
2015	A Method for Improving Two-line Element Outlier Detection Based on a Consistency Check	Advanced Maui Optical and Space Surveillance Technologies Conference Maui Hawaii September 15 -18, 2015	Y. Zhao, K. Zhang, J. Bennett, J. Sang, S. Wu	Conference Poster Presentation
2015	A Method for Improving Two-line Element Outlier Detection Based on a Consistency Check	Advanced Maui Optical and Space Surveillance Technologies Conference Maui Hawaii September 15 -18, 2015	Y. Zhao, K. Zhang, J. Bennett, J. Sang, S. Wu	Conference proceedings

2015 – 2016

Publications & Presentations

Other publications and presentations

Date	Title	Published in/presented at:	Authors	Publication type
2015	The interaction between the Earth's magnetic field and the spinning of the satellites	Australian Space Research Conference	D. Kucharski, J. Bennett	Conference presentation
2015	The 2015 St. Patrick's Day superstorm: Effects in the near-Earth space environment	Australian Space Research Conference	B. A. Carter, E. Yizengaw, C. Lin, R. Pradipta, R. Norman, T. Tseng, J. Bennett, R. Bishop, M. Francis, M. Terkildsen, K. Groves, R. Caton, K. Zhang	Conference presentation
2015	A Method for Improving Two-line Element Outlier Detection Based on a Consistency Check	Australian Space Research Conference	Y. Zhao, K. Zhang, J. Bennett, J. Sang, S. Wu	Conference Poster Presentation
2015	The 2015 St Patrick's Day Geomagnetic Superstorm: Effects in the near-Earth space environment and impacts on technologies	Australian Space Research Conference	B. A. Carter, R. Norman, J. Bennett, K. Zhang	Presentation
2015	The St Patrick's Day Geomagnetic Storm: Preliminary Results	SERC Colloquium	B. A. Carter	Presentation
2015	Reliable Orbit Determination	SERC Colloquium	S. Gehly	Presentation
2015	3-D Ray tracing techniques based on geometrical optics	SERC Colloquium	R. Norman	Presentation
2015	Progress report – Research Project 2	SERC Colloquium	K. Zhang	Presentation
2015	Recent advances in predicting the occurrence of ionospheric scintillation events for satellite communications and GNSS applications	BoM/SWS Space Weather Workshop	B. A. Carter	Presentation
2015	Extreme space weather events and the potential cost to modern-day society	BoM/SWS Space Weather Workshop	B. A. Carter	Presentation
2015	The impacts of the St. Patrick's Day superstorm on selected technologies	AGU Fall Meeting	B. A. Carter	Presentation
2015	Estimation as Applied to Space Situational Awareness	SPACE Technical Forum	R. A. Norman, J. Bennett, K. Zhang	Presentation

2015 – 2016

Publications & Presentations

Other publications and presentations

Date	Title	Published in/presented at:	Authors	Publication type
2015	Australian Research in SSA	ESA	K. Zhang	Presentation
2015	Overview of SSA Related Research and Developments from the RMIT SPACE Research Centre	University of Brunswick Germany	K. Zhang	Presentation
2015	Optus Satellite Systems: End-user perspectives and collaborations	SERC Participants' Colloquium	A. Edwards	Presentation
2015	Progress Report – Research Project 3	Optus Site Visit	J. Bennett	Oral presentation
2015	Spin Analysis	Optus Site Visit	D. Kucharski	Oral presentation
2015	Progress Report – Research Project 3	SERC Participants Colloquium	J. Bennett	Oral presentation
2015	Spin Determination and Modelling of Space Debris	SERC Participants Colloquium	D. Kucharski	Oral presentation
2015	Sparse Data OD	SERC Short Course – An Introduction to Astro-dynamics	J. Bennett	Oral Presentation
2016	An investigation into the COSMIC radio occultation outage during the 2015 St. Patrick's Day geomagnetic storm	ICGPSRO	B. A. Carter, K. Zhang, B. Schreiner, M. Sleziak, R. Norman, A. C. Kellerman, S. Gehly, J. Bennett, T. Tseng, J. Le Marshall, A. J. Mannucci, N. L. Yen	Conference presentation
2016	RP1 Overview and Update	SERC Research Colloquium, Canberra	C. Smith	Conference presentation
2016	Development of the Sodium Guide Star laser	SERC Research Colloquium, Canberra	J. Webb	Conference presentation
2016	Development of requirements for a SERC catalogue and database	SERC Research Colloquium, Canberra	D. Kooymans	Conference presentation
2016	An Analysis of the 2016 Hitomi (ASTRO-H) breakup event	SERC	J. Bennett	Internal Report

2015 – 2016

Publications & Presentations

Other publications and presentations

Date	Title	Published in/presented at:	Authors	Publication type
2016	An Analysis of the 2016 Hitomi (ASTRO-H) breakup event – Contributions by SKF	SERC	S. Flegel	Internal Report
2016	RP3 Update	SERC Research Colloquium	J. Bennett	Presentation
2016	Space Debris Spin Dynamics Measurement, Analysis and Modelling at SERC	SERC Research Colloquium	D. Kucharski	Presentation
2016	Towards Relaxing the Spherical Assumption for Accurate Orbit Propagation of Space Debris	SERC Research Colloquium	M. Lachut	Presentation
2016	GPU Computing for Orbital Propagation & Collision Assessment	SERC Research Colloquium	M. Möckel	Presentation
2016	Analysis of the ASTRO-H breakup and its impact on the collision risk of intact objects	SERC Research Colloquium	S. Flegel	Presentation
2016	Analysis of the ASTRO-H breakup and its impact on the collision risk of intact objects	“Feast of Facts” RSAA Colloquia at ANU	S. Flegel	Presentation
2016	Geo situational awareness: An operators point of view and update	SERC Research Colloquium	A. Edwards	Presentation
2016	The occurrence of equatorial plasma bubbles around the world during the 2015 St. Patrick’s Day geomagnetic storm: Modelling and observations	First VarSITI Symposium	B. A. Carter, E. Yizengaw, R. Pradipta, J. M. Retterer, K. Groves, C. Valladares, R. Caton, C. Bridgwood, R. Norman, K. Zhang	Conference presentation
2016	Space Environment Research Centre - A New Initiative for Australian Space Tracking	HPLA/DE	S. Gehly, K. Zhang, J. Bennet, R. Norma, B. Carter, S. Wu, Y. Zhao, M. Afful, C. He, T. Kodikara	Conference presentation
2016	Estimation Techniques to Support Laser Maneuver of Orbital Debris	HPLA/DE	S. Gehly, Y. Yang, K. Zhang, J. Bennet, R. Norman, B. A. Carter, S. Wu	Poster

Appendix 2

SERC Scholarship Students

SERC scholarships for 2015 – 2016

Degree	Student name	University	Research topic
PhD	Paul Sibley	ANU	Laser written waveguides for an optical phased array head
BSc (Hons)- Applied Science	Samantha Le May	RMIT	Modelling the future evolution of the orbital debris population
PhD	Chanyong He	RMIT	Precise thermospheric density correction for robust orbit determination and prediction of low-earth-orbit objects
PhD	Michael Afful	RMIT	Space debris characterisation for reliable orbit determination and prediction
PhD	Timothy Kodikara	RMIT	Enhancing Atmospheric Mass Density Modelling for Space Situational Awareness
PhD	Kyle Damm	UQ	Multipoint, multi-objective geometric optimisation of a hypersonic launch vehicle
PhD	Pierpaolo Toniato	UQ	Mach 12 Scramjet testing in X3 expansion tube
PhD	Samuel Stennett	UQ	Flow Condition Optimisation and Characterisation for a New Large Scale Reflected Shock Tunnel
PhD	Timothy Cullen	UQ	Re-entry Shock Layer Thermography
PhD	Samuel Francis	ANU	A Robust Laser Interferometer for Multiplexed Measurements of Optical Path Lengths
PhD	Yang Zhao	RMIT	Two-line element data quality control and its application in Space Situational Awareness
PhD	Shasidran Raj	ANU	Space Debris Tracking using Continuous Wave Laser
PhD	Elliott Thorn	ANU	Design of SERC Adaptive Optics Laser Guide Star Facility
PhD	Anna Zovaro	ANU	Adaptive Optics for Space Debris Manoeuvring and Astronomy
PhD	Michael Copeland	ANU	Advanced Imaging and Wavefront Sensing for Satellite Laser Ranging and Tracking.
BSc & BEng R&D (Hons)	Alexander Stuchbery	ANU	Design, Construction & Testing of a Camera Latency Measurement Device
PhD	Jesse Cranney	UoN	Predictive control of adaptive optics systems for observations and tracking of space objects and debris
PhD	Lyle Roberts	ANU	Development of a high-power optical phased array for space debris tracking and manoeuvring
PhD	Alpha Bah	UTS	Reconfigurable Ultrawide band Tightly Coupled Arrays

Table 07: all scholarships are supplementary except Samantha Le May and Alexander Stuchbery, who have received undergraduate scholarships.