



# Cooperative Research Centre for Space Environment Management

Annual Report  
2014 - 2015



Australian Government  
Department of Industry,  
Innovation and Science

**Business**  
Cooperative Research  
Centres Programme

This report has been prepared in accordance with the 2014-15 Cooperative Research Centres Programme Annual Report Guidelines and is submitted to comply with the requirements of Section 4 of the Guide.

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

## Contact SERC

Space Environment Research Centre Ltd  
AITC2, Mount Stromlo Observatory  
Weston Creek ACT 2611

PO Box 238, Mawson ACT 2607

T +61 2 619 70157

E [info@serc.org.au](mailto:info@serc.org.au)

W [www.serc.org.au](http://www.serc.org.au)



[www.facebook.com/serc.aus](https://www.facebook.com/serc.aus)



[@serc\\_aus](https://twitter.com/serc_aus)

## Contents

Report from the Chair.....	5
Report from the CEO .....	6
1.0 Executive Summary .....	7
1.1 Achievements .....	7
1.2 Risks and Impediments .....	9
1.3 End-User Environment .....	10
1.4 Impacts .....	10
2.0 Research .....	11
Highlights and Achievements.....	11
SERC Research Programs .....	12
2.1 Performance against Activities .....	12
2.2 Education and Training .....	17
2.3 SME Engagement.....	20
3.0 Results.....	21
3.1 Utilisation and Commercialisation.....	21
3.2 Intellectual Property Management .....	22
3.3 Communications .....	24
4.0 Resources.....	28
4.1 Governance - Board, Committees and Key Staff .....	28
4.2 Participants.....	35
4.3 Collaboration .....	35
4.4 Financial Management .....	38
5.0 Other Activities .....	39
6.0 Additional Requirements .....	39
6.1 External Reviews.....	39
6.2 Internal Reviews .....	39
7.0 Glossary of Terms .....	41
Appendix 1 – 2014-15 Publications and Presentations .....	42
Appendix 2 – SERC Scholarship Students.....	48

## Figures

Figure 1:	Timeline of achievements in SERC's foundation year .....	8
Figure 2:	SERC research programs .....	12
Figure 3:	Optus Satellite Systems facility at Belrose NSW .....	16
Figure 4:	SERC PhD student Lyle Roberts.....	19
Figure 5:	EOS Space Research Centre at Mt Stromlo Observatory (large dome) .....	20
Figure 6:	Mt Stromlo Observatory, Weston Creek ACT .....	22
Figure 7:	SERC communication tiers .....	24
Figure 8:	Participants' lunch and tour of the SERC facilities .....	25
Figure 9:	The SERC website (www.serc.org.au) .....	26
Figure 10:	SERC CEO, Dr Ben Greene presenting at ILRS .....	26
Figure 11:	Ceremonial signing of the NICT OPA.....	27
Figure 12:	Promotional poster for the World Record Stargazing event with SERC acknowledged as a sponsor .....	27
Figure 13:	View from the EOS Space Research Centre, Mt Stromlo Observatory, Canberra .....	28
Figure 14:	SERC organisational structure as at 30 June 2015 .....	34
Figure 15:	The ANU Advanced Instrumentation Technology Centre (AITC) at Mount Stromlo Observatory.....	36
Figure 16:	NICT 1.5m telescope in Tokyo, Japan.....	37
Figure 17:	SERC CEO, Dr Ben Greene, giving a tour of Mt Stromlo facilities .....	39
Figure 18:	The SERC Annual Research Program Review Process .....	40

## Tables

Table 1:	Key research achievements - Research Program 1 .....	13
Table 2:	Key research achievements - Research Program 2 .....	13
Table 3:	Key research achievements - Research Program 3.....	14
Table 4:	Key research achievements - Research Program 4 .....	14
Table 5:	In-progress and incomplete milestones at 30 June 2015 .....	15
Table 6:	Students involved with SERC Research .....	19
Table 7:	SERC Board Members .....	29
Table 8:	Board Member attendance at SERC Board meetings for 2014-15.....	30
Table 9:	SERC Board Committee Members as at 30 June 2015.....	30
Table 10:	SERC Research Management Committee Members.....	32
Table 11:	Attendance at 2014-15 Board Committee Meetings.....	33
Table 12:	Names and time commitments of key staff.....	34
Table 13:	Collaboration between research participants .....	36
Table 14:	Collaboration between research participants and end-user participants .....	37
Table 15:	Glossary of terms included in this report.....	41
Table 16:	Formal publications produced during 2014-15.....	42
Table 17:	Other publications and presentations produced during 2014-15 .....	44
Table 18:	SERC PhD students for 2014-15 .....	48
Table 19:	SERC undergraduate student for 2014-15 .....	48

## Report from the Chair

I am pleased to report that the CRC for Space Environment Management, under the administration of the Space Environment Research Centre Limited (SERC), has had a successful first year. We were delighted that the CRC received the full funding in its bid and we worked quickly to establish the formal structures that enable the core business of the CRC - research and education - to proceed.

SERC's members include two universities: the Australian National University and RMIT University; three industry partners: EOS Space Systems, Lockheed Martin (USA) and Optus Satellite Network; and one international public sector research agency, the Japanese National Institute of Information and Communications Technology. I thank all the members for their support in getting SERC established.

I would also like to thank our CEO, Dr Ben Greene, and his management team, all the researchers in the CRC, and my fellow Board members for their extensive and various contributions.

By our combined efforts we will work to make major contributions towards tracking and eventually removing existing debris, in order to protect space infrastructure from collisions through the use of early warning systems and by limiting the addition of new debris.

We recognise that this is a problem of international proportions and part of our ongoing work will be to engage further partners from around the world, to garner enough support and collaboration to make speedy and significant headway on this endeavour.



Mary O'Kane  
Chair

## Report from the CEO

*Quality of life in the developed world depends on a diversity of expensive infrastructure, much of which is underpinned by satellite technology.*

Every day, we access details of time and weather; use traffic and navigation assistance; we take calls, receive emails and check bank account balances on our phones. Every day, service personnel monitor emergency situations, carry out search and rescue missions and initiate law enforcement operations. Every day, we go about our lives supported by communication and information systems that rely on the uninterrupted use of satellite technology. The more we depend on these technologies, the greater the risk to us if they are suddenly and indefinitely unavailable.

SERC was established to preserve access to the space environment through two specific research objectives. First we will establish more efficient and effective space debris collision avoidance for active satellites by providing significant improvements in predicting the orbits of debris, allowing active satellites to manoeuvre in time. Secondly we aim to manoeuvre space debris away from collisions using lasers on the earth.

This is a large and ambitious program requiring close collaboration between researchers, industry and space agencies through shared resources and knowledge. To ensure the technology and capability is retained SERC is engaging the education sector with scholarship funding to better establish core technologies in society. We are employing emerging leaders in the field, providing scholarships to up and coming researchers and pooling the resources of multinational organisations to access or develop the high powered equipment needed to further our aims.

Our primary task is to preserve space for our future. In addition we aspire to foster Australian innovation and to propel our nation to the forefront of this field, stimulating industries, jobs and prosperity in our wake.

Through our website and social media channels we are working to develop community awareness of the issue of space debris and to keep the public informed of progress in addressing this threat. We have made an excellent start.



Ben Greene  
Chief Executive Officer

## 1.0 Executive Summary

The CRC for Space Environment Management is operated by the Space Environment Research Centre (SERC). SERC is an Australian Public Company, Limited by Guarantee and is funded through the Department of Industry, Innovation and Science's Cooperative Research Centres Programme and 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 will consolidate currently-independent research efforts to achieve a critical mass of effort to form a platform for new investment, by providing:

- a transparent 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 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

*There have been many highlights during our establishment year including:*

- **Board Established.** The SERC Board of Directors was established on 10 April 2014.
- **Agreements Signed.** The Commonwealth Agreement was executed on 16 June 2014. The Essential Participants Agreement was executed on 15 September 2014. The Other Participants' Agreements were executed by December 2014.
- **Governance.** The Principles for CRC Governance (Oct 2012) were adopted by the Board on 3 September 2014.
- **Board Committees.** Five committees have been established to advise Directors.

- **Transparency and Accountability.** All Members accepted the CRC Constitution and Participant Agreements which link IP rights, entity voting rights and Participants' cash and in-kind contributions to the Research Programs. In-kind contributions are assessed for both quantity and efficacy.
- **Financial Management and Discipline.** SERC has successfully implemented modern cost controls to limit administrative costs to less than \$1 million in the first year of operations, allowing over 70% of all cash funds to flow to research and education programs.
- **Policies.** The following policies and procedures were developed and implemented:
  - Strategic Plan;
  - IP Principles;
  - In-Kind Contributions Assessment Policy;
  - Risk Management Plan and Register;
  - Conflict of Interest Policy and Register;
  - Work Health and Safety Policy;
  - Privacy Policy;
  - Delegations of Authority Policy;
  - Circulating Board Resolutions Procedure;
  - Transition Plan; and
  - Communications Strategy, including Media Policy and Social Media Policy.
- **Registered Charity.** SERC has been recognised by the ACNC as a registered charity and is seeking deductible gift recipient status.
- **Research Management Committee.** SERC has established a strong Research Management Committee with international membership to oversee the research process, review progress and assess the efficacy of in-kind contributions.
- **Research Program Review.** Prior to awarding research contracts to Participants, an internal review of proposed objectives, budgets and milestones was conducted by SERC in conjunction with Participants.
- **Research Program Contracts.** SERC awarded R&D contracts to two Essential Participants for the execution of two of the four SERC Research Programs.

- **New Participants.** Discussions with a number of potential Participants are progressing. A review of gaps in SERC capabilities in late 2015 will indicate the attributes that would be sought in new members if SERC extended further membership opportunities.
- **Collaboration.** SERC Research Programs involve collaboration between most Participants at research, education and end-user levels.  
Collaboration with end-users including Optus Satellite Systems (Optus), Lockheed Martin Space Systems Company (LMC) and EOS Space Systems (EOSSS) is informing SERC research efforts regarding end-user requirements and utilisation.  
International collaboration with the Japanese National Institute of Information and Communications Technology (NICT) and LMC ensures SERC research has a global focus. In addition, collaboration with EOSSS, LMC and university Participants provides SME, industry and education perspectives.
- **Scholarships.** Four post-graduate students were awarded SERC top-up scholarships and one undergraduate scholarship was awarded.
- **Website.** The SERC website went live in September 2014 ([www.serc.org.au](http://www.serc.org.au)). It is updated regularly in-house and is hosting growing traffic.
- **Branding and Media.** SERC rapidly achieved its initial branding and market recognition targets. Media attention has been positive, and much is diverted to SERC's tertiary Participants to enhance the education message.
- **Launch.** The CRC was launched at Parliament House on 2 December 2014 by the Hon Ian Macfarlane MP. Activities around the launch included extended media interviews, ceremonial signing of the Japanese Participant Agreement and laboratory tours.
- **Facebook.** SERC's Facebook page went live in March 2015. Relevant posts are made regularly and interest in the page is building.
- **Annual Review of Research.** As part of SERC's annual review program, the annual research review commenced in May 2015. The review was conducted by a working group of the Research Management Committee led by Dr Ben Greene (Chair) and involved the SERC Research Program Leaders. The SERC Research Program review process is further discussed in Section 6 of this Annual Report.

### Timeline of SERC Achievements

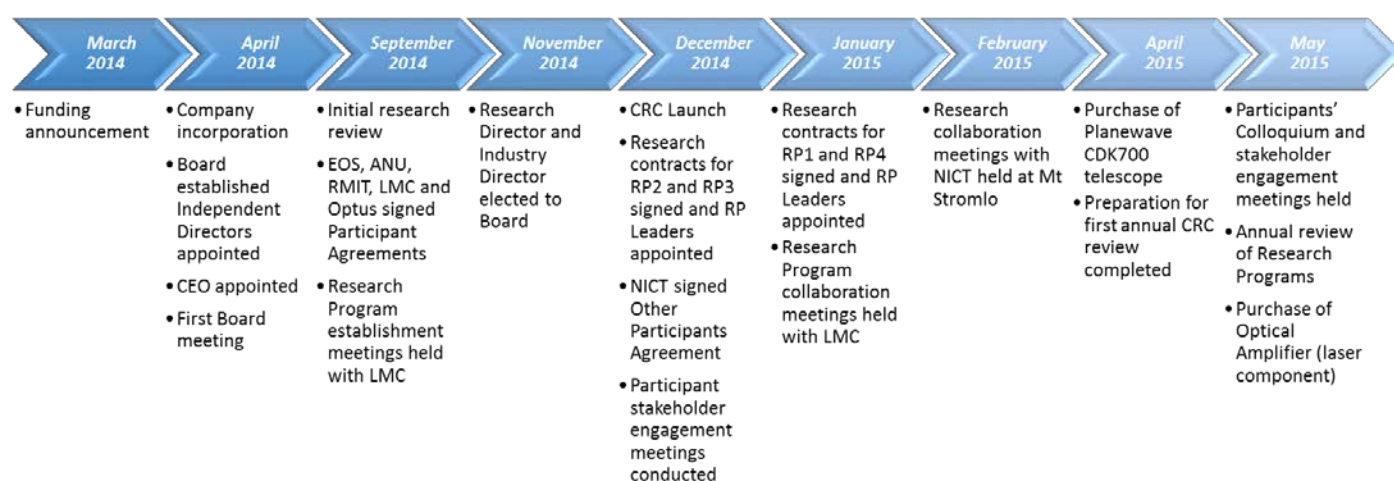


Figure 1: Timeline of achievements in SERC's foundation year



## 1.2 Risks and Impediments

*There were no major impediments in the establishment year of the CRC. However some matters warrant mention:*

- **Expectations.** Although Participants joined SERC expecting an innovative approach, the collective impact of extreme budgeting, outsourcing research management, retrospective valuation of in-kind contributions, linkages between benefits and contributions, absolute transparency and hard-headed process was significant. This was always going to cause some issues, but the good will and commitment which Participants have brought to this issue has been heartening.
- **Research Outsourcing.** Half of SERC Research Programs are contracted to Participants to manage. The contracts were placed after commercially bruising negotiations where all Essential Participants agreed to in-principle terms which are advantageous to SERC. The outsourcing allows SERC to run a leaner structure and focus on its mission. This process was time consuming as it involved cultural change, commercial negotiation and careful conflict of interest resolution.
- **Conflict of Interest.** SERC is industry-led. The principles for avoiding a conflict of interest are simple, but the processes required to transparently implement those principles are complex and have consumed considerable effort.
- **Establishment Resources.** Human and financial resources were tight during the start-up phase which resulted in minor delays in developing policies and procedures. SERC is now on target with the implementation of the necessary policies and procedures.

### Risk Mitigation

The SERC Risk Management Committee has been established to identify and manage risks and impediments to the successful delivery of SERC objectives. SERC maintains a comprehensive Risk Register which is reviewed regularly by the Risk

Management Committee and a report on strategies to mitigate risks and impediments which maintain a high residual impact rating is reported to the Board at every Board meeting.

Key risks identified during the reporting period and strategies adopted to address these risks include:

- Loss of key researchers was identified as a business continuity risk. This risk is being addressed through a range of controls including quarterly project meetings, international linkages to identify and recruit subject matter experts and annual stakeholder reviews. This is supported by Research Management Committee oversight.
- Innovation below national and international comparators has been identified as a research risk. This risk is being addressed through the Research Management Committee, annual Research Program review and regular communication with Participants and CEO liaison with national and international Participants.
- Inability to attract PhD students in our establishment year was identified as an education risk. This was due to the promotional window for scholarships falling in the agreement negotiation period when funding was not secure. To address this the scholarships were underwritten by SERC University Participants. This risk has now been mitigated.

The following risks were initially rated as having a high impact. Through the implementation of risk and impediment management strategies they have been revised to having a moderate impact:

- Unsafe WHS working arrangements and practices – mitigation measures include development of policies, awareness and induction training, appointment of a first aid and WHS officer and regular reporting.
- Intellectual Property (IP) not protected or not properly commercialised – this has been addressed by appointing experienced Research Program Leaders, implementing IP management guidelines and the inclusion of

robust non-disclosure and IP protection clauses in Participant Agreements and staff and student contracts.

- Failure to ensure SERC creates wealth and benefits for its Participants – mitigation measures include CEO and Chair six monthly meetings, regular liaison with international partners, ongoing negotiations and vetting of potential new Participants and review of Research Program quarterly reports by the Research Management Committee.
- Failure of one or more Research Programs to deliver outcomes – management measures include ongoing end-user engagement and Research Management Committee review of the Research Programs.
- Insufficient quality and quantity of in-kind commitments from Participants – this has been addressed by reconfirming Participant contributions and annual quantitative and, from 2016, qualitative assessment of contributions.

### 1.3 End-User Environment

SERC's mission and strategic direction involves developing and commercialising technologies to reduce the threat to space-based infrastructure from space debris. End-user engagement and collaboration is necessary to ensure that SERC research achieves this outcome.

Three of the six SERC Participants can be classified as end-users. Optus have a substantial investment in space-based infrastructure and are highly motivated to protect their investment. EOSSS and LMC develop commercial technologies to prevent space debris collisions. These companies represent end-users of SERC IP

which they will utilise to develop the next generation of space environment management technology.

*End-user involvement has been achieved during the reporting period through the following activities:*

- Regular communication and meetings with end-user Participants to identify requirements and opportunities for collaboration.
- Ongoing industry liaison and engagement.
- Participation at national and international symposia to identify new end-user Participants.
- Participants' colloquium 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 to identify emerging trends in relation to space technologies and space debris mitigation. This enables the Board to make decisions to ensure that SERC's 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

At the time of writing this Annual Report, no substantial changes to the expected impact of SERC as outlined in the Impact Tool (EIPIT) have been identified. It is expected that any changes to the expected outputs, usages or impacts and their associated probabilities will become evident as the CRC matures and research outcomes become clearer.

## 2.0 Research

### Highlights and Achievements

- Four Research Programs established
- All continuing research milestones for the reporting period either complete or in progress
- All utilisation and education milestones for the reporting period met
- Established project teams involving one or more Participants for each program
- Quarterly reporting and in-kind assessment methodology established
- Review of Research Programs completed

The Space Environment Research Centre (SERC) research aims to develop technologies and strategies that preserve the space environment for social, economic and national capability benefits. This will be achieved through the delivery of the SERC research objectives outlined below:

**Objective 1:** Minimise, and if possible prevent, any impact of space debris on the well-being of society.

**Objective 2:** Develop technologies which could be commercialised to generate revenue for continuing this effort beyond an initial period of Commonwealth funding.

**Objective 3:** Contribute significantly to the pool of space technology researchers and technologists.

Minimising the impact of space debris on space operations involves three different but linked efforts. In order of maturity they are:

**Satellite Manoeuvre.** Satellites can be moved from the path of debris provided the orbital positions of both the satellite and the debris are known. The magnitude of the manoeuvre and the amount of fuel required to complete it

depend on the accuracy of the orbital information for the two objects.

The development and deployment of laser space debris tracking technology in Australia provides an existing platform for developing highly accurate collision predictions.

*SERC research builds on this capability with improvements in tracking and data analysis to provide a leap-ahead in collision prediction to improve **satellite manoeuvre** operations.*

**Debris Manoeuvre.** It is more efficient to move the space debris as satellite manoeuvres consume fuel and reduce the useful lifetime of the satellite significantly. Ground-based manoeuvre of space debris using lasers has been proposed by numerous authors, but to date no on-orbit demonstration has been successful.

*SERC research aims to extend the laser tracking capabilities already demonstrated in SERC Participant Research Programs and to perform experiments to determine the feasibility of space **debris manoeuvres**.*

**Debris Removal.** The long-term objective for debris management is the removal of space debris. Globally, there are various proposals for space debris removal.

Most experts agree that very large objects will require some type of new launch activity to allow a physical connection to be made to the debris, to encourage de-orbit. These larger objects are well known, and are in relatively stable orbits due to their significant weight.

For smaller and lighter objects it may be viable to gradually degrade the debris orbit using remote thrusting with lasers or other devices. These objects far outnumber the heavier objects referred to above and any de-orbit solution would be a major contribution.

*SERC research ultimately aims to achieve **debris removal** through debris manoeuvres using high powered lasers.*

## SERC Research Programs

SERC Research Programs are interlinked and involve collaboration and expertise from SERC Participants to deliver the SERC Research Objectives.



Figure 2: SERC Research Programs

### 2.1 Performance against Activities

During the 2014-15 reporting period, SERC laid a solid foundation to achieve the SERC research objectives and delivered 12 of the 15 year one research milestones.

In addition, two more of the 15 research milestones are in progress and clear strategies are in place to ensure that these milestones are met during the next reporting period.

One milestone has been discontinued as an alternative solution has been identified.

#### Key research achievements

The key research achievements for each Research Program are outlined in tables one to four.

Table 1: Key research achievements - Research Program 1


Tracking, Characterisation and Identification of Space Objects Key Research Achievements	
<ul style="list-style-type: none"> <li>Developed a high precision sensor for geostationary earth orbit (GEO) objects for use with astrometric plate solutions.</li> <li>Ordered a test-bed sensor and a visible light spectrometer for target spectral characterisation.</li> <li>Developing astrometric software for use on the new sensor.</li> <li>Developed the draft specifications for the schema and database.</li> <li>Developed the system requirements for laser tracking data.</li> <li>Implemented test hardware for the measurement of satellite light curves and spin rates.</li> </ul>	 <p><b>Professor Craig Smith</b> Research Program Leader</p>

Table 2: Key research achievements - Research Program 2


Orbit Determination and Predicting Behaviours of Space Objects Key Research Achievements	
<ul style="list-style-type: none"> <li>Analysed data formats and techniques for sensor data integration with two-line element (TLE) analyses as the primary focus.</li> <li>Identified that preliminary research on reliable orbit determination studies using multiple TLE data to determine an orbit for satellites does not perform as well for debris objects as it does for satellites.</li> <li>Developing methods to identify erroneous TLEs. These methods will be modified and applied to the detection of erroneous TLEs. This research involves close collaboration with other SERC Participants.</li> <li>Implementation and testing of satellite orbit prediction in the analysis of the St Patrick's Day geomagnetic storm. Early results indicate that the track errors of the Gravity Recovery and Climate Experiment (GRACE) satellites are significantly influenced by the geomagnetic storm as expected. The analysis will be extended to additional satellites.</li> <li>Further development on the three dimensional numerical ray tracing technique has been achieved. Simulation of optical, global navigation satellite system (GNSS) and high frequency (HF) signal paths from the ground to GEO altitudes is now possible. Realistic models of the ionosphere and magnetic field have also been incorporated into the simulation process.</li> <li>Expected progress was achieved towards the algorithms and methodologies related to precise orbit determination, reliable orbit determination, semi-analytical satellite theory, atmosphere modelling, radio occultation and space weather impact.</li> </ul>	 <p><b>Professor Kefei Zhang</b> Research Program Leader</p>



Table 3: Key research achievements - Research Program 3



Space Asset Management Key Research Achievements	
<ul style="list-style-type: none"> <li>The data flow methodology for the high accuracy catalogue has been established and research is being undertaken to define the schema to be used for the database design and orbit element generation. Close collaboration between SERC Participants has facilitated strong progress.</li> <li>New methods for determining the spin rate and orientation of orbiting objects using light curves have been developed. Excellent progress has been made and a new method termed "Phase Dispersion Minimisation" has been developed to determine spin period of orbiting objects. This method has already been shown to significantly outperform frequency analysis: it yields a unique solution and works for slowly spinning satellites, unlike frequency analysis.</li> <li>Magnetic interaction between the earth's magnetic field and metallic satellites has also been studied since the spin prediction models require an accurate estimate of the magnetisation parameter of a satellite. This is progressing well for spherical test satellites and future work will include irregular object shapes.</li> <li>A method is being developed to determine 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 are being analysed and initial results are promising. A reliable area-to-mass ratio is critical for accurate orbit determinations, predictions and for conjunction assessments with sparse observation data.</li> <li>Extensive analysis has also been carried out on TLE data showing that using multiple TLEs for better orbit determinations fails in some circumstances. In some cases using a single TLE with the SGP4 propagator outperforms a high accuracy fit to pseudo-observations generated from multiple TLEs for debris objects. Previous results for satellites indicated that using multiple TLEs resulted in better accuracy.</li> <li>Completed the analysis of existing conjunction analysis methods and developed a conjunction assessment software package. This software reproduces the conjunction assessments delivered by SOCRATES using TLE data. This is an important research milestone for this program.</li> </ul>	 <p><b>Dr James Bennett</b> Research Program Leader</p>

Table 4: Key research achievements - Research Program 4

Preservation of the Space Environment Key Research Achievements	
<ul style="list-style-type: none"> <li>Coordination of laser safety has commenced. This will be extremely important when higher power lasers are deployed later in the program.</li> <li>Completed the initial analysis of a deformable mirror design solution and researchers have initiated the development of end-to-end modelling and a simulation suite.</li> <li>Identified potential sources for high power Continuous Wave (CW) lasers and conducted feasibility assessment of combining lasers from internal (SERC) and external (vendor) sources to achieve the projected power levels.</li> <li>Internal development of guide star laser was accelerated to provide backup for commercially-sourced lasers which may not achieve SERC-imposed price-performance requirements.</li> <li>Integration of natural guide star Adaptive Optics (AO) system has been completed. This critical system will likely be available ahead of program schedule.</li> <li>A testbed setup for phased laser demonstrations and high powered amplifiers has been initiated.</li> <li>A full feasibility review of the proposed debris manoeuvre experiment was conducted through the Research Management Committee, resulting in a more conservative experimental design.</li> </ul>	 <p><b>Dr Ben Greene</b> Research Program Leader</p>



**Status of In-progress or Incomplete Milestones***Table 5: In-progress and incomplete milestones at 30 June 2015*

Output	Research Milestone	Status
R1.6 - Develop Multi-Colour Guide Star Systems for Tip-Tilt Correction. The output from this program will be dual colour laser guide stars (Rayleigh and Sodium) that sample different frequencies that will allow the absolute tip-tilt of the atmosphere to be measured, improving astrometric accuracy. Two guide stars, sensors and software will be produced.	R1.6.1 - Analysis completed and specifications finalised for new hardware/software developments	This milestone was an alternative (backup) approach for achieving the high performance required from the AO (adaptive optics) system for improved tracking in RP1 and improved beam delivery in RP4. However, progress under other milestones now promises to provide the performance required with only a single colour laser guide star. This is a lower risk and cheaper solution, and work on the multi-colour laser guide star can be discontinued.
R2.1 - Develop Intelligent Systems for Real-Time Precision Orbit Determination (POD) for 'Controlled' Satellites. This Research Program will develop real-time POD software platforms that will 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, such as space weather.	R2.1.1 - Analysis and specifications for new hardware/software developments completed	This effort has been hampered by unexpectedly slow recruitment of research staff. Notwithstanding, a large amount of relevant literature has been collected and reviewed. A PhD student has been recruited and is working on space situational awareness (SSA) related research. Improved employment terms have been established and more aggressive recruitment has commenced in order to achieve this milestone in the next reporting period.
R2.2 - Development of Reliable Orbit Determination (ROD) Algorithms and Software. Advanced ROD platform for 'uncontrolled' space objects. The ROD software platform developed will comprise versatile orbit determination algorithms that employ data from a variety of different sources; e.g. two-line elements data and satellite laser ranging.	R2.2.1 - Data formats and techniques for sensor data integration analysed	This effort has been hampered by unexpectedly slow recruitment of research staff. Current effort has been concentrated on two-line element analyses and limited work is done toward the laser tracking aspect. This is an ongoing effort. A large quantity of literature has been reviewed, data formats and techniques for sensor data integration are being analysed and accelerating process is being achieved. Improved employment terms have been established and more aggressive recruitment has commenced in order to achieve this milestone in the next reporting period.

## End-user Involvement

SERC's end-user Participants contribute significantly to inform and shape SERC Research Programs. SERC engages with end-users on many levels through meetings, colloquia, stakeholder consultation and industry liaison.

The SERC Research Management Committee has been established to set and review research priorities, provide advice on utilisation and commercialisation opportunities and represent the interests of end-user organisations to ensure that SERC research objectives are aligned with industry requirements.

SERC representatives attend and contribute to strategic industry conferences, workshops and symposia to further engage with end-user organisations including owners of space-based infrastructure and assets; space research organisations; and Australian and international government agencies.

SERC Chief Executive Officer, Dr Ben Greene presented an address at the International Laser Ranging Service (ILRS) 19<sup>th</sup> Workshop on Laser Ranging. Dr Greene's presentation on "New Applications for Laser Ranging and Space Debris" was well received. This prestigious workshop has been the key international meeting place for space tracking for 40 years and a permanent international working group of the ILRS has subsequently been formed to support space debris tracking.

A Participants' colloquium was held at the Mount Stromlo in May 2015. This event created a deeper understanding of the research activities across the four Research Programs and provided a catalyst for accelerating collaboration between Research Programs, Participant organisations and end-users.

To ensure that SERC research meets end-user needs, some collaboration approaches were developed at the colloquium including:

- Detailed presentations from Optus, EOSSS and LMC allowed researchers to better understand end-user environments and requirements.
- Invitations were issued to Participant organisations and SERC scholarship students to visit the Optus Satellite Systems facility at Belrose to gain a further appreciation of end-user requirements.
- Research Program Leaders undertook to identify areas where Optus knowledge and access to data, equipment or facilities could assist the research effort.

It was agreed that the colloquium was a valuable forum for interaction, collaboration and clarifying end-user requirements.

SERC will coordinate research colloquia twice a year to support its research programs and facilitate continued end-user involvement and collaboration on meeting end-user needs.



Figure 3: Optus Satellite Systems facility at Belrose NSW



## Future Research Directions

As at 30 June, no recommendations for changes to future research directions have been submitted for Board approval. However, a full review of the SERC Research Programs is being conducted by the Research Management Committee and a report will be submitted to the Board and the Department of Industry, Innovation and Science in late 2015.

## SERC Publications

SERC Research Programs produced a total of 50 publications in 2014-15. 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 is provided at Appendix 1.

The number of formal publications is expected to increase as SERC research progresses, collaboration matures and Research Programs build further momentum.

## 2.2 Education and Training

SERC has a strong focus on education and training and is working with our national and international partners to identify and recruit the best and brightest students for our Research Programs. A list of 2014-15 SERC students is provided at Appendix 2.

SERC has met all of the 2014-15 education and training commitments through the allocation of scholarship funding for six top-up scholarships in each of the SERC Research Programs.

In addition, SERC awarded one undergraduate and four Higher Degree by Research (HDR) top-up scholarships, representing good progress towards SERC's second year education milestones.

Three HDR scholarship students are conducting research under the supervision of the Australian National University (ANU) and one student is under the supervision of RMIT University (RMIT). All projects align with one or more of SERC Research Programs.

SERC awarded an undergraduate scholarship to a student who has shown great promise in the space science industry. Anna Zovaro attends the University of Sydney and participated in the ANU Summer Research Scholar program in December 2014. This scholarship has enabled her to continue the SERC related research she commenced as a summer scholar. SERC will sponsor Anna to attend the Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) in Hawaii in September 2015 where she has been invited to present a paper.

AMOS is regarded as the premier space surveillance conference in the world. SERC will also financially support RMIT and ANU PhD students to participate at AMOS as delegates and presenters. SERC researchers and Research Program Leaders are also being supported to attend AMOS to further their understanding and to foster global collaboration.

SERC will continue to work with ANU and RMIT in 2015-16 to identify and recruit exceptional students for SERC Research Programs.

It has become evident that there is a shortage of high calibre PhD candidates in SERC subject areas in Australia, SERC has expanded the focus of our space science education program by undertaking the following activities:

- 1) SERC is offering a full HDR scholarship in 2016 to attract an exceptional PhD candidate.
- 2) SERC awarded an undergraduate scholarship to a promising honours student to encourage her to pursue a SERC PhD research project. Funds have been set aside for a second undergraduate scholarship in 2015-16.
- 3) SERC has written to every Deputy Vice Chancellor Research (DVCR) in Australia to promote SERC scholarship opportunities. This will be followed up with one on one meetings during the next reporting period.

SERC has initiated a promotional campaign targeting leading Australian universities offering courses in space science and related fields to attract PhD, Masters and fourth year undergraduate students to the program.

In addition to this, a range of targeted activities are planned for 2015-17 including:

- SERC will present at a range of academic events, aimed at capturing the best HDR students in 2015-16. In addition, SERC will launch a student newsletter and host networking activities.
- SERC will sponsor a STEM teachers' summer program in December 2015.
- A series of road shows to promote SERC Scholarship opportunities to Australian Universities are scheduled for 2016-17.

- 4) SERC will further explore opportunities for students to undertake internships with national and international Participants and satellite operators.

### **Student Involvement in SERC's Activities**

During the establishment year SERC research teams have been resourced and funded and students allocated to SERC supervisors where appropriate. During the 2014-15 reporting period four SERC students applied for funding to attend the AMOS Conference. SERC has approved this funding support and the students will travel to AMOS in September 2015. In addition the SERC Chief Executive Officer will meet with the students to discuss their research projects and SERC research activities.

SERC students are an integral part of the research team. As part of assisting their development into fully-fledged researchers it is anticipated that students engaged with SERC research will participate in most activities scheduled for 2015-16 including Participants' colloquia, a visiting Professor Lecture series and field trips such as to the Optus Satellite facility.

### **End-user Interaction with Students**

SERC end-users participate in developing and conducting education/training activities in a variety of ways, including the supervision of postgraduate students.

Optus gave 'in principle agreement' at the Participant's colloquium to support SERC scholarship students by inviting them to spend

time at their satellite facility at Belrose. This will enable students to gain a greater appreciation of end-user requirements of space-based infrastructure owners and operators.

EOSSS is the lead organisation in Research Program 1. In this capacity, EOSSS contributes to the supervision of SERC PhD and undergraduate students conducting research relating to this program.

SERC supports postgraduate students by awarding top-up scholarships to exceptional candidates undertaking Higher Degrees by Research in relevant fields. This strategy has been developed to build capacity in the industry and create a sustainable pipeline of graduates in space sciences and related fields.

SERC top-up scholarships are promoted to all Australian universities offering research opportunities in aligned fields of study including mathematics, engineering, physics, dynamic database management, adaptive optics, astrodynamics, atmospheric sciences, geodesy, astrophysics, geomatics, laser engineering, laser guide star adaptive optics, laser physics, photonics and satellite positioning.

Students can study at their own university whilst building synergies with SERC. As SERC students and researchers may work from different locations, mechanisms to mentor, supervise and support them are being developed to help students build networks, share knowledge and collaborate with SERC researchers and other SERC scholarship recipients.

SERC has implemented the following support measures for students:

- Regular communication with research coordinators at their respective universities;
- SERC administrative support with agreements, travel and event attendance;
- Scholarship funding includes additional financial support for students to attend industry conferences and workshops to develop industry connections; and
- SERC scholarship students are encouraged to attend research colloquia to collaborate and interact with SERC researchers and 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 the CRC and SERC research matures exciting opportunities will be available nationally and internationally for SERC students.

*Table 6: Students involved with SERC research*

Degree	Name	Research Topic	Financial Assistance
Undergraduate B. Eng/B. Science	Anna Zovaro	Test of the LGS beam pointing mirror	ANU summer scholarship
Undergraduate Honours	Anna Zovaro	FPGA based AO	SERC undergraduate scholarship
Undergraduate B. Engineering	Laila Sezin	New concepts in GEO debris tracking	ANU summer scholarship
Postgraduate PhD	Yang Zhao	Two-line Element data quality control and its application in Space Situational Awareness	RMIT scholarship CSC scholarship SERC top-up scholarship
Undergraduate B. Engineering	Alex Stuchbery	Thermal and vibration characterization of EOS 1.8Mm Coude train	ANU summer scholarship
Undergraduate B. Engineering	Elliot Thorn	Thermal and vibration characterization of EOS 1.8Mm Coude train	ANU summer Scholarship
Postgraduate Master Astronomy & Space Systems	Hugues Poincelin	Design of the Beam Transfer Optics for the 1.8Mm EOS telescope LGSF	Partial ANU support
Postgraduate PhD	Lyle Roberts	Internally sensed optical phased array	APA SERC top-up scholarship
Postgraduate PhD	Shasidran Raj	Coherent laser ranging with CW lasers	ANU scholarship SERC top-up scholarship
Postgraduate PhD	Samuel Francis	Displacement sensing architectures with digital interferometry.	APA SERC top-up scholarship



*Figure 4: SERC PhD student Lyle Roberts*

## 2.3 SME Engagement

*It is estimated that the worldwide economic value of space asset investment is greater than \$2 trillion.*

Satellites are costly to build, launch and operate. Consequently there are no small to medium enterprise (SME) satellite owners or operators in Australia. Optus are a SERC end-user Participant and are the only commercial satellite operator in Australia.

Although Australia is home to some of the best space technologists in the world, the high entry costs and investment required to participate in this industry mean there are a limited number of SMEs in Australia operating in this sector.

This highlights the importance of SERC engaging with and supporting SMEs to build critical mass and a sustainable space industry in Australia.

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.

A further, much broader market segment comprises companies who provide goods or services which rely on satellite technology. This industry sector has much greater SME representation. It is too soon for SERC to engage with this broad market segment, however strategies are being developed to engage with this broader industry sector from 2017.

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

- **SME Participants.** EOSSS is an SME Participant and represents the interests of SMEs within SERC. Professor Craig Smith is the CEO and Technical Director of EOSSS and the leader for Research Program 1. Through leading the RP1 research team, Professor 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 Chief Executive Officer, Dr Ben Greene and EOSSS CEO Professor Craig Smith.
- **Communications Strategy.** The SERC Communications Strategy identifies SMEs as key stakeholders and outlines strategies for communication and engagement with SMEs within Australia and overseas.



*Figure 5: EOS Space Research Centre at Mt Stromlo Observatory (large dome), used for SERC research activities*

## 3.0 Results

### 3.1 Utilisation and Commercialisation

SERC achieved its utilisation milestones for 2014-15 through regular meetings with Participants culminating in the delivery of a Participants' colloquium in May 2015.

Key themes of the colloquium were conceptual design aspects of the research activities; research progress in the initial six months of operation; and end-user involvement and collaboration. The colloquium was well attended by Participants and was highly beneficial for collaboration and advancement of the research activities.

*Outcomes of the May 2015 colloquium:*

- A deeper appreciation of end-user requirements through presentations from end-user Participants EOSSS, Optus and LMC.
- Opportunities for further collaboration with Optus and additional end-users were identified.
- Invitations for SERC researchers and students to visit the Optus Satellite Systems facility at Belrose were issued.
- Greater appreciation of the research activities being conducted by other Participants and within other Research Programs was achieved. This will foster further interaction and collaboration between organisations and Research Programs going forward. This will be supported by SERC through increased communications, social media and the coordination of bi-annual colloquia.

A second Participants' colloquium will be held in November 2015. Early feedback indicates that this event will be well attended. In addition members of the Research Management Committee will participate. This will enable committee members to gain a deeper appreciation of the research progress, facilitate interaction with SERC researchers and inform decisions relating to the future directions and funding of the Research Programs.

As a result of these activities, all utilisation and commercialisation milestones were achieved as at 30 June 2015.

#### Research Outputs Uptake by end-users

SERC has implemented a number of strategies to ensure end-user uptake of the SERC research outputs.

*End-user engagement activities during the reporting period:*

- **Stakeholder Meetings.** Regular communication and meetings with end-user Participants to identify areas for collaboration have occurred throughout 2014-15. The SERC Chief Executive Officer has conducted meetings with industry stakeholders such as Optus to ensure that SERC research is meeting expectations. Regular meetings also occur with end-user Participants EOSSS and LMC. Discussions between LMC, EOSSS and the Australian National University (ANU) have highlighted a potential application for the Lyle Roberts Optical Phased Array system (Lyle Roberts is a SERC scholarship student) in the development of a scalable high-power Continuous Wave laser. This laser may be deployed in RP4 manoeuvre of space debris experiments. These collaborations have been further augmented through meetings at the Research Program Leader and researcher levels.
- **Research Management Committee.** The SERC Research Management Committee (ResMC) guides and directs SERC Research. Optus, EOSSS and LMC are represented on this committee to ensure that end-user requirements inform research activities. In addition the ResMC monitors worldwide developments and directions and identifies emerging trends in relation to space technologies and space debris mitigation. This enables the Board to make decisions to ensure that SERC's strategic direction aligns with its end-user participants.
- **Industry Liaison.** Ongoing industry liaison and meetings with national and international end-users is achieved through attendance at



conferences, symposia and workshops. This ensures SERC is well informed about end-user requirements at a global level and is abreast of emerging industry developments.

- **Participants' Colloquium.** The colloquium enables end-user Participants to provide valuable insight into the technical and operational challenges they experience on a daily basis. Conceptual research design is informed through this process and the direction and scope of SERC research modified accordingly. The SERC colloquium also promotes greater collaboration and interaction between research teams and end-users. This ensures that SERC research outputs better meet end-user requirements. As SERC research matures, Participants' colloquia will greatly inform SERC commercialisation activities. It is anticipated that this will foster a smoother uptake of research outputs by end-users.

#### **Commercialisation/Utilisation Arrangements**

SERC commercialisation and utilisation activities focused on delivering the first year utilisation milestones. The vehicle for achieving this milestone was the Participant's colloquium

delivered in May 2015. The colloquium involved SERC industry Participants including LMC and EOSSS. Through identifying end-user requirements, the colloquium provided an opportunity for understanding and designing SERC commercialisation and utilisation activities.

As the CRC matures and the research gains momentum, commercialisation and utilisation activities will expand to include consultation with non-participant, industry, SME and end-user organisations.

#### **New or Improved Products, Services or Processes and Benefits to End-users**

The initial focus has been on resourcing and establishing the Research Programs and delivering SERC's year one research milestones. Excellent progress has been achieved in all areas of research, however SERC has not developed any new or improved products, services or processes so specific benefits to end-users cannot be quantified at this stage. SERC did not generate any spin off companies during the first year of operation.

It is expected that during the next reporting period several software and procedural developments will be completed and reported.



*Figure 6: Mt Stromlo Observatory, Weston Creek ACT*

### **3.2 Intellectual Property Management**

During the 2014-15 reporting period SERC developed and implemented appropriate intellectual property (IP) management principles. These principles draw on the recommendations of the Intellectual Property Management Guide for Cooperative Research Centres developed for the CRC Branch of the Department of Industry, Innovation and Science by Dibbs Barker.

The implementation of sound IP management practices will ensure that IP developed through the SERC research activities will be identified, recorded and commercialised effectively and equitably in accordance with SERC Commonwealth and Participant Agreements.

In addition, the ResMC provides advice and recommendations to the Board in relation to IP protection and management.

### Details of IP Currently Held by the CRC

Excellent progress has been achieved in all areas of research, however SERC has not developed any new or improved IP during the establishment year.

It is expected that during the next reporting period the IP of several software and procedural developments will be reported.

### Intellectual Property Management

During the establishment year, SERC adopted the following IP Principles:

1. SERC will develop and commercialise technologies to reduce the threat to space-based infrastructure from space debris.
2. SERC will undertake four research projects towards this objective, and SERC members will be entitled to a share of the intellectual property rights arising from a research project in proportion to their contributions, both financial and in-kind, with SERC entitled to a share arising from the contribution of Commonwealth funds, as stipulated in the Participant Agreements.
3. SERC will transparently assess the actual, aggregate contributions of members to each research project to allow equitable allocation, among members, of rights to IP.
4. SERC will establish boundaries between background IP contributed to a SERC research project and new IP developed through SERC research, to clearly establish SERC rights.
5. Early in the planning stages of each SERC research project, SERC will establish a roadmap of IP milestones towards commercially useful technology, and research project leaders will be required to report against these milestones. These will be updated annually.
6. SERC will set aside appropriate funds for the timely protection of IP and ensure that publication of research is controlled to ensure IP protection is not degraded.
7. SERC will use arm's length commercial licences for the exploitation of IP. Members will have no exclusive or preferred right to any SERC IP, but must bid for IP licences on the same terms as non-members.
8. Licence fees received by SERC from a licensee of SERC IP must be distributed among SERC and its members in accordance with their shares, however a member which has successfully bid for a licence for SERC IP will be entitled to a discount on those fees in proportion to that member's share, provided the member waives rights to income distributions from SERC from those fees.
9. SERC will place a priority on the achievement of a commercial return in the form of licence fees for SERC IP.
10. SERC will apply the "Intellectual Property Management Guide" provided by the Commonwealth as a guide for SERC IP management processes.

*In adhering to these principles, SERC has engaged the following management strategies:*

- Identification and recording of Background IP is in progress.
- Establishment of a publications register. All publications, including theses and conference presentations are registered along with pdf copies. This provides additional mechanisms to ensure that SERC IP is captured prior to public disclosure.
- Inclusion of IP and confidentiality clauses in Participant, employee and student contractual arrangements provides further protection to SERC IP.
- SERC IP management principles and practices training for SERC employees, researchers and students will be undertaken from 2016.

A review of SERC IP management will be conducted in 2016 by the Research Management Committee to ensure that Participants are operating in accordance with these principles.

SERC is ensuring that all IP arrangements are in keeping with the National Principles of IP and will make every reasonable effort to gain benefit for Australia from Centre IP. No registered IP was sold, transferred or licensed for commercialisation during the reporting period.

### 3.3 Communications

SERC communications objectives will evolve over the five year funding period. Communications in years one and two will concentrate on attracting the required resources, including scholarship students, researchers and participants, and refining the Research Programs.

The SERC Communications Strategy was approved by the Board of Directors in April 2015. In addition, policies for Social Media and Media engagement have been adopted. These documents will be reviewed annually to ensure they are effectively meeting requirements.

Communications during year one focused on:

- Solution-focused messages tailored around SERC's core activities.
- Innovative technology that is being developed by SERC researchers.
- SERC researchers, their expertise in the industry, vision, direction and achievements.
- Participants, their stories, experiences and achievements.

The SERC Communications Strategy employs a tiered approach with a different level of engagement and method of delivery tailored for each stakeholder group.

- Tier 1:* Board of Directors, Executive staff and Commonwealth Government
- Tier 2:* Participants and SERC Corporate staff
- Tier 3:* Research and educational institutions space agencies, Industry (including SMEs and multinationals) and end-users
- Tier 4:* General public

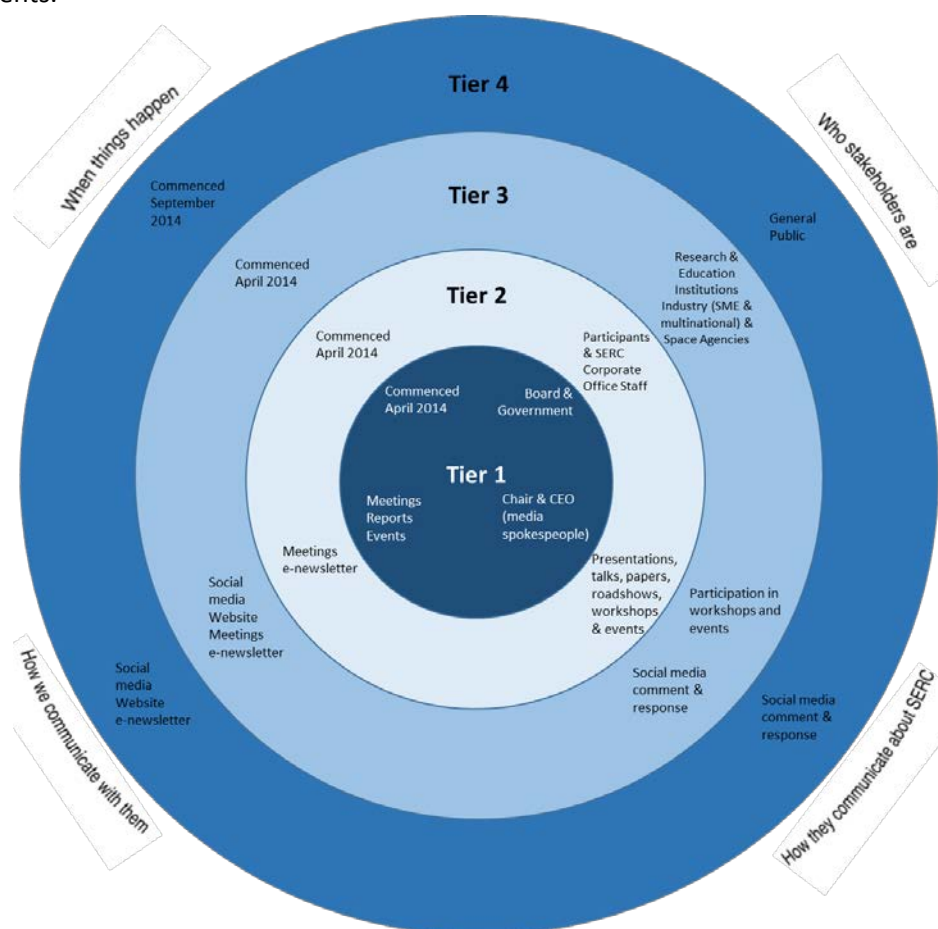


Figure 7: SERC communication tiers



## Internal Communications

SERC highly values communications and relationship management. Internal communication activities during the reporting period have focused largely on Tiers 1 and 2 and on ensuring all parties are engaged through the SERC establishment and resourcing phase. As the CRC matures, communications will be more evenly weighted across all four tiers as strategies to educate and engage with wider business and community audiences are implemented.

*Year one internal communication activities included:*

**Participants' Colloquium.** A Participants' colloquium was held at the Mount Stromlo Observatory in May 2015. The workshop operated as a formal commencement to researcher, Participant and end-user collaboration. This event provided the opportunity for all involved to gain an overview of the planned research activities and to commence shaping the future direction and collaboration for each project.

**Regular Meetings.** 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.

**Supplementary Launch Activities.** The official SERC launch was attended by representatives from all Participant organisations. As many participants had travelled interstate and internationally, a range of supplementary events were held in conjunction with the launch including:

- A dinner meeting to facilitate collaboration between SERC Participants prior to the launch was hosted by SERC Directors. Representatives from Optus, LMC, EOSSS, ANU and RMIT attended this event.
- An official dinner was held after the launch to celebrate the signing of the NICT agreement. Corporate gifts were exchanged and collaboration meetings held. Representatives of the Japanese Embassy also attended.
- A Participants' lunch and tour of the SERC facilities was attended by national and international Participants and representatives from the Japanese Embassy. A Participants' photo was taken and distributed to attendees to commemorate the occasion.



*Figure 8: Participants' lunch and tour of the SERC facilities were part of the launch activities*

## External Communications

Targeted external communications activities have been undertaken to establish SERC's identity and create platforms for engagement.

**Branding.** An identity for the CRC, under the banner of SERC was created and embedded in communications materials over the course of the year. The logo conveys a futuristic feel that represents the forward thinking focus of the CRC and clearly displays the name of the centre to help establish SERC's identity.

**Press and Radio Coverage.** SERC garnered considerable media attention through activities surrounding the SERC launch. This included articles in ABC News, BBC, Sydney Morning Herald, Newcastle Herald and interviews on ABC radio. In addition, SERC featured in selected industry journals including *Room: the space industry journal* published by the Aerospace International Research Centre in Vienna. SERC also featured in the CRC Association September 2014 edition of *Know How* magazine.

**Website.** Developing a website that acts as a central portal for Research Programs and outcomes, education, scholarships, media, news and events has been a focus during our establishment year. The SERC website was launched in September 2014 and includes details of our participant organisations.

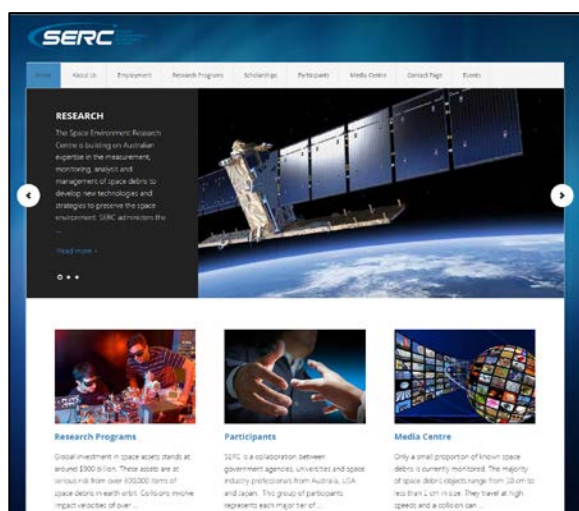


Figure 9: The SERC website ([www.serc.org.au](http://www.serc.org.au))

**Social media.** A SERC Facebook profile ([www.facebook.com/serc.aus](https://www.facebook.com/serc.aus)) has been established. Further expansion of SERC social

media presence, including the establishment of Twitter and LinkedIn accounts is planned for the next reporting period.

**Events.** Space debris is a global issue. As a world leader in space debris management, SERC representatives are invited to present at international conferences and symposia. SERC Chief Executive Officer delivered an address at the ILRS 19<sup>th</sup> International Workshop on Laser Ranging in Annapolis, Maryland in October 2014. This event is the premier Satellite Laser Ranging industry event and was attended by over 180 space industry professionals from 23 countries. Participation at this level generates considerable interest in SERC research and helps identify opportunities for international collaboration.



Figure 10: Dr Ben Greene presenting at ILRS

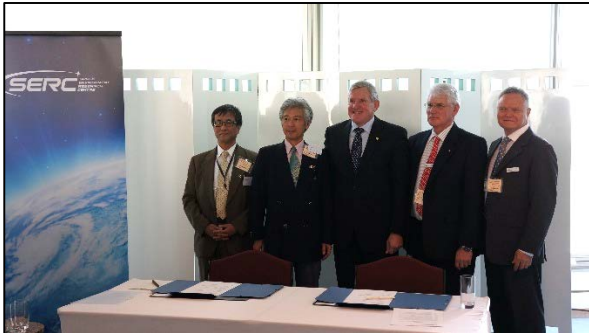
**International Delegations.** SERC hosted a number of international delegations during the reporting period. These delegations included representatives from the Japanese and US embassies and the Korea Astronomy and Space Sciences Institute.

**Launch.** The Hon Ian Macfarlane MP, Minister for Industry and Science, launched the CRC for Space Environment Management at Parliament House, Canberra in December 2014. The event was attended by over 60 guests including the Minister, Senator Kate Lundy, Departmental Secretaries, Federal and ACT Government representatives, US and Japanese Embassy representatives, Participants, industry associations and industry representatives.

The SERC website received its highest web traffic to that date on the day of the launch.

Media attention for the launch included an interview with Lish Fejer on ABC 666 radio.

A ceremonial signing of the NICT Other Participant Agreement (OPA) followed the official launch proceedings.



*Figure 11: Ceremonial signing of the NICT OPA  
L-R: Dr Hiroo Kunimori, Dr Fumihiko Tomita,  
Minister Ian McFarlane MP, Mr Brett Biddington  
and Dr Ben Greene*

**Sponsorship:** SERC has furthered external communication through sponsorship of selective events.

Sponsorship during 2014/15 included a morning tea at the 19<sup>th</sup> International Workshop on Laser Ranging in Annapolis, Maryland. Sponsorship of this event generated interest and awareness on an international stage to a targeted space industry audience.

In addition, SERC sponsored the ANU Mount Stromlo World Record Stargazing Event for the greatest number of stargazers in one location at one time. The World Record was achieved with 1869 stargazers in attendance. This event appealed to the general public and had an extensive reach.

The SERC logo was included on the boxes for 10,000 telescopes that were distributed to sky-watchers all around Australia.

Media attention generated around this event included coverage in The Canberra Times, The Australian, The Brisbane Times and on the ABC.



*Figure 12: Promotional poster for the World Record Stargazing event with SERC acknowledged as a sponsor*

Although the stargazing event will be held in August 2015, marketing and promotion and sponsorship commitments fell in the 2014/15 reporting period and it has therefore been included in this Annual Report.



## 4.0 Resources

### 4.1 Governance - Board, Committees and Key Staff

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

SERC's Strategic Plan was adopted on 18 March 2015. The plan 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 to be more advanced collectively 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.

SERC has laid the groundwork to achieve these Strategic Objectives and will continue to build on this strong foundation in the coming years.

The SERC Board of Directors was established with three Independent Directors on 10 April 2014. A Research Director and Industry Director were elected to the Board on 18 November 2014. There were no further changes to Directors during the reporting period.




The Board is responsible for the governance and operations of SERC. The Board adopted the Cooperative Research Centres Programme Principles for CRC Governance (October 2012) on September 3, 2014.

While the Board has overall responsibility for SERC operations, it has delegated a range of powers, duties and responsibilities to its committees and executive management. This has been formalised by the SERC Delegations of Authority Policy adopted in March 2015 which is updated periodically.





*Figure 13: View from the EOS Space Research Centre, Mt Stromlo Observatory, Canberra*

Table 7: SERC Board Members

Name and Positions Held	Experience and Key Skills
	<p><b>Professor Mary O'Kane</b></p> <p>Chair (Independent)</p> <p>Chair of the Nominations and Remuneration Committee</p> <p>Professor Mary O'Kane has extensive expertise in the fields of science and engineering. She is the NSW Chief Scientist and Engineer; the Executive Chairman of Mary O'Kane &amp; Associates, a company that advises governments, universities and the private sector on innovation, research, education and development. Professor O'Kane chairs various boards including the CRC for Spatial Information, Development Gateway, Development Gateway International and the University of Tasmania's Institute of Marine and Antarctic Studies. Professor O'Kane is also a director of Business Events Sydney and the Capital Markets CRC as well as being a trustee for the New Zealand Antarctic Research Institute. From 1996-2001 Professor O'Kane was the Vice-Chancellor of the University of Adelaide.</p>
	<p><b>Mr Brett Biddington AM</b></p> <p>Independent Director</p> <p>Chair of the Audit Committee</p> <p>Mr Brett Biddington AM is the founder of Biddington Research Pty Ltd specialising in space and cyber security matters.</p> <p>Mr Biddington is Treasurer and a board member of the Institute for Regional Security (a Canberra based 'think tank'). He is the Chief Executive responsible for organising the International Astronautical Congress in Adelaide in 2017. He sits on several advisory boards and committees concerned with the governance of Australia's space and astronomy activities and with science, technology, engineering and mathematics (STEM) education and outreach. He holds Adjunct professorial appointments at Edith Cowan University in Perth and at RMIT University (RMIT) in Melbourne. In 2012, Mr Biddington was admitted as a Member of the Order of Australia (AM) for services to the Australian space sector.</p>
	<p><b>Ms Elizabeth Whitelaw</b></p> <p>Independent Director</p> <p>Chair of the Contracts and Licences Committee</p> <p>Chair of the Risk Management Committee</p> <p>Ms Elizabeth Whitelaw has extensive board and private sector experience. She is a former senior partner of Minter Ellison and Member of the Australian Institute of Company Directors.</p> <p>Ms Whitelaw has performed both chair and non-executive director roles for government-owned corporations, partnership boards, advisory bodies and not-for-profit organisations including Minter Ellison's National Partnership Board, Canberra Chair of Partners, 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.</p>



Name and Positions Held	Experience and Key Skills
	<p><b>Dr Steve Gower</b></p> <p>Research Director</p> <p>Appointed: 18 November 2014</p> <p>Dr Steve Gower is the Director for Research Collaborations and Partnerships at RMIT University and is responsible for liaison with key stakeholders including government, industry, universities, CRCs and research organisations both domestically and internationally. Dr Gower is also responsible for the establishment of international research laboratories, research contracts, IP and commercialisation, and has served on various boards and committees.</p>
	<p><b>Mr Rod Drury</b></p> <p>Industry Director</p> <p>Appointed: 18 November 2014</p> <p>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 Lockheed Martin Space Systems Company (LMC). He is also a member of the Executive council of the Space Industry Association of Australia. As well as serving on the Board, Mr Drury is Chief Operating Officer for SERC.</p>

The Board of Directors met nine times during the 2014-15 reporting period with meetings held on the following dates:

**2014:** 23 July, 3 September and 20 November

**2015:** 21 January, 18 March, 23 April, 27 May, 28 May and 19 June

The Public Officer during the reporting period was Professor Craig Smith, Company Secretary.

*Table 8: Board Member attendance at SERC Board meetings for 2014-15*

Committee Member	Role	Board Meetings	
		Number eligible to attend	Number attended
Professor Mary O'Kane	Chair (Independent)	9	9
Mr Brett Biddington	Independent Director	9	9
Ms Elizabeth Whitelaw	Independent Director	9	8
Dr Steve Gower	Research Director	7	7
Mr Rod Drury	Industry Director	7	6

## SERC Board Committees

*Table 9: SERC Board Committee Members as at 30 June 2015*

Audit Committee	Contracts and Licences Committee	Nominations and Remuneration Committee	Risk Management Committee	Research Management Committee
<ul style="list-style-type: none"> <li>Mr Brett Biddington (Chair)</li> <li>Mr Rod Drury</li> <li>Dr Steve Gower</li> </ul>	<ul style="list-style-type: none"> <li>Ms Elizabeth Whitelaw (Chair)</li> <li>Professor Mary O'Kane</li> <li>Dr Steve Gower</li> </ul>	<ul style="list-style-type: none"> <li>Professor Mary O'Kane (Chair)</li> <li>Ms Elizabeth Whitelaw</li> <li>Dr Steve Gower</li> <li>Mr Brett Biddington</li> </ul>	<ul style="list-style-type: none"> <li>Ms Elizabeth Whitelaw (Chair)</li> <li>Dr Ben Greene</li> <li>Mr Rod Drury</li> </ul>	<ul style="list-style-type: none"> <li>Dr Ben Greene (Chair)</li> <li>Dr Fumihiko Tomita</li> <li>Dr Moriba Jah</li> <li>Mr Rod Drury</li> <li>Professor Craig Smith</li> <li>Mr Andrew Edwards</li> </ul>

The SERC Board is advised by various Board Committees including the Audit Committee, Contracts and Licences Committee, Nominations and Remuneration Committee, Risk Management Committee and the Research Management Committee.

#### **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 three times a year at regular intervals.

Moore Stephens was appointed as the independent auditor. The Audit Committee also seeks expert advice from RSM Bird Cameron as required.

It was identified during the reporting period that a qualified accountant would add value to the Audit Committee processes and recruitment of a suitably qualified person to join the audit committee has commenced.

#### **Contracts and Licences Committee**

This committee meets three times a year or as required to assist the board in investigating potential conflicts of interest for SERC. A monthly report outlining any contract or expenditure 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 but at least once a year to assist the Board in fulfilling its corporate governance responsibilities in regard to the selection and appointment of Board Directors and in its responsibilities for appointing and reviewing the CEO and overview of the Executive team as well as the system of remuneration and benefits for the Executive Team.

#### **Risk Management Committee**

The Risk Management Committee meets three times a year or as required to identify, monitor and advise the Board and Executive on potential 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, SERC are brought to the attention of the Board.

#### **Research Management Committee**

The Research Management Committee meets four times a year or as required. This committee has been established to advise the Board on decisions relating to the Research Programs, including setting research priorities, identifying education and student development opportunities and providing quarterly recommendations to the Board on utilisation, intellectual property, in-kind assessments and commercialisation issues.





The Committee provides expert advice to the Board 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 principal functions of the Research Management Committee are 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.

The Committee has representation from international research participants, end-user participants, SME participants and an independent international space industry professional. SERC is currently recruiting a second independent member to join the Research Management Committee.

Table 10: SERC Research Management Committee Members

Name and Special Responsibilities	Experience and Key Skills
	<p><b>Dr Ben Greene</b> Chair of the Research Management Committee</p> <p>Dr Ben Greene is the founder and Chief Executive Officer of Electro Optic Systems (EOS) and 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.</p> <p>Dr Greene is also the author of numerous patents and the architect of a number of international space tracking systems.</p>
	<p><b>Dr Fumihiko Tomita</b> Member of Research Management Committee</p> <p>Vice President National Institute of Information and Communications Technology Japan</p> <p>Dr Fumihiko Tomita is responsible for research strategy in the National Institute of Information and Communications Technology (NICT) Japan, and also for the leadership in 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.</p> <p>After an appointment as Assistant Professor, Dr Fumihiko Tomita 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.</p>
	<p><b>Dr Moriba Jah</b> Independent member of Research Management Committee</p> <p>Director Advanced Sciences and Technology Research Institute for Astrodynamics Air Force Research Laboratory US Airforce</p> <p>Dr 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.</p> <p>While working at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, CA as a spacecraft navigator he was 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. Dr Jah is a world-recognized subject matter expert in astrodynamics-based Space Situational Awareness sciences and technologies.</p>
	<p><b>Mr Rod Drury</b> Member of Research Management Committee</p> <p>Director International Strategy and Business Development Lockheed Martin Space Systems Company</p> <p>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 Lockheed Martin Space Systems Company. He is also a member of the Executive council of the Space Industry Association of Australia.</p> <p>As well as serving on the Board and Research Management Committee, Mr Drury is Chief Operating Officer for SERC.</p>





Name and Special Responsibilities		Experience and Key Skills
	<b>Professor Craig Smith</b>	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.
	Member of Research Management Committee  CEO and Technical Director EOS Space Systems	Professor Smith has also held positions within Electro Optic Systems (EOS) as CEO EOS Technologies (the US subsidiary of EOS) and Head of Research and Development.
	<b>Mr Andrew Edwards</b>	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.
	Member of Research Management Committee  Manager Satellite Support Optus Satellite Systems	Andrew has supported mission analysis, station keeping, propulsion subsystem and fuel life estimation for all five generations of Optus's spacecraft.

Table 11: Attendance at 2014-15 Board Committee Meetings

Committee Member	Board Committee									
	Audit		Contracts & Licences		Nominations & Remuneration		Risk Management		Research Management	
	A	B	A	B	A	B	A	B	A	B
Professor Mary O'Kane			5	5	1	1				
Mr Brett Biddington	1	1	5	5	1	1				
Ms Elizabeth Whitelaw			5	5	1	1	2	2		
Dr Steve Gower	1	1			1	1				
Mr Rod Drury	1	1					2	2		
Dr Ben Greene							2	2	1	1
Dr Moriba Jah									1	-
Dr Fumihiko Tomita									1	1
Professor Craig Smith									1	1
Mr Andrew Edwards									-	-

A – Number of meetings held during the time the Committee Member held office

B – Number of meetings attended

## 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 5 shows the organisational structure of SERC. Table 5 shows the names and time commitments of key staff, including the Chief Executive Officer and Research Program Leaders.

SERC ORGANISATION CHART AS AT 30 JUNE 2015

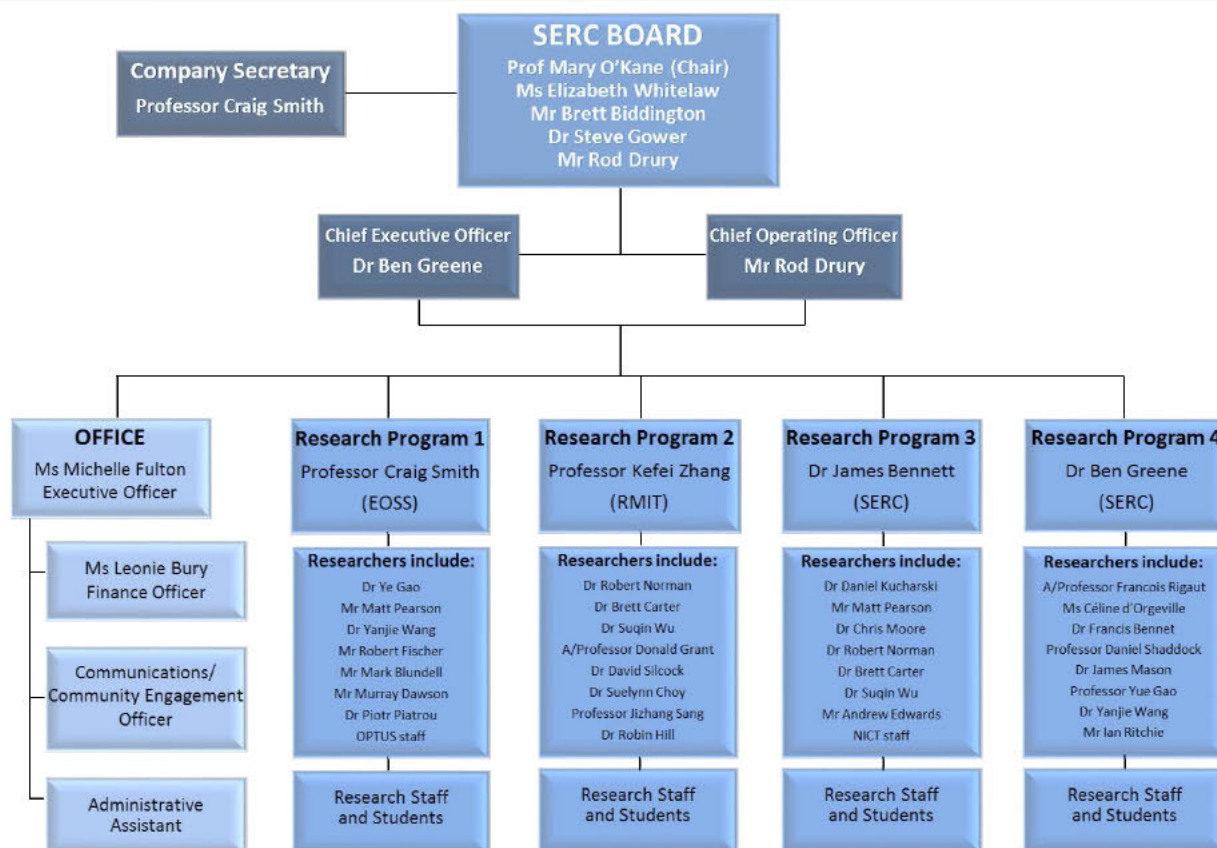


Figure 14: SERC organisational structure as at 30 June 2015

Table 12: Names and time commitments of key staff

Name	Organisation	Role	FTE
Dr Ben Greene	Electro Optic Systems	Chief Executive Officer Research Project Leader – RP4	75%
Ms Michelle Fulton	Electro Optic Systems	Executive Officer	80%
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%

## 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 reporting period including:

### Essential Participants:

 <p><b>Australian National University</b></p> <p>The Australian National University ABN: 52 234 063 906</p> <p>Essential Participant University Participant</p>	 <p><b>RMIT UNIVERSITY</b></p> <p>RMIT University ABN: 49 781 030 034</p> <p>Essential Participant University Participant</p>	 <p><b>EOS SPACE SYSTEMS</b></p> <p>EOS Space Systems ABN: 11 008 587 451</p> <p>Essential Participant SME Industry and End-User Participant</p>
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### Other Participants:

 <p><b>NICT</b></p> <p>National Institute of Information and Communications Technology</p> <p>Other Participant (Japan) Research Participant</p>	 <p><b>yes</b></p> <p>Optus Satellite Systems ABN: 15 091 789 945</p> <p>Other Participant End-User Industry Participant</p>	 <p><b>LOCKHEED MARTIN</b></p> <p>Lockheed Martin Space Systems Company</p> <p>Other Participant (USA) Industry and End-User Participant</p>
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## 4.3 Collaboration

### Collaboration between Research Participants

SERC Participants include representation from industry (SME and multinational corporations), universities and end-users. The success of SERC will depend on collaboration and sharing of risk between these Participant groups.

Research collaboration between participants has covered a range of research areas including determining the accuracy of reference data, adaptive optics, laser guide star development and laser procurement and/or development.

University Participant ANU is collaborating with SME participant EOSSS and multinational industry participant LMC to develop a scalable high-powered Continuous Wave (CW) laser.

SERC collaborations are often extensions of prior pooled research and consequently the barriers to entry are low and sharing of both knowledge and risk amongst collaborators is established.



These collaborations are generally industry-led to ensure a commercial focus is achieved. Details of SERC collaboration between research Participants, industry and end-users during the reporting period are provided below.

*Table 13: Collaboration between research participants*

Research Program	Collaboration participants
Research Program 1	EOS Space Systems (industry, SME, end-user and research) Lockheed Martin Space Systems Company (industry; multinational; end-user; research) Australian National University (research)
Research Program 2	National Institute of Information and Communications Technology (research) OPTUS Satellite Systems (industry, end-user) RMIT University (research)
Research Program 3	OPTUS Satellite Systems (industry, end-user) EOS Space Systems (industry, SME, end-user and research) Australian National University (research) RMIT University (research)
Research Program 4	EOS Space Systems (industry, SME, end-user and research) Lockheed Martin Space Systems Company (industry; multinational; end-user; research) Australian National University (research)



*Figure 15: 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*



## Research and End-user Collaboration

Three of the six SERC Participants are end-users of SERC research outcomes. During the 2014-15 reporting period there was significant collaboration between SERC participants and end-users. Collaboration activities occurred informally at the research level and formally through participation in the SERC colloquium, collaboration meetings and site visits.

Table 14 shows the collaboration that occurred between research Participants and end-user Participants in the 2014-15 reporting period.

*Table 14: Collaboration between research participants and end-user participants*

RP	Collaboration participants
RP 1	Australian National University (research) EOS Space Systems (research and end-user) Lockheed Martin Space Systems Company (research and end-user)
RP 2	RMIT University (research) OPTUS Satellite Systems (end-user)
RP 3	SERC (research) OPTUS Satellite Systems (end-user) EOS Space Systems (research and end-user)
RP 4	Australian National University (research) EOS Space Systems (research and end-user) Lockheed Martin Space Systems Company (research and end-user)

## External Linkages

External linkages and collaboration also occurred in the 2014-15 reporting period. This activity took place in Australia and internationally. Highlights included collaborative research activities at the Space Research Institute of the Austrian Academy of Science at the Satellite Laser Ranging Observatory in Graz, Austria.

The main focus of this joint research activity was space debris attitude motion measurements and modelling. This research focuses on the spin determination of defunct satellites located on low earth orbit, as well as middle and high earth orbits. The results are used to model the

interaction between the passive spacecraft and the earth's magnetic field which exerts forces and torques on the metallic objects. The magnetic interaction models will help to improve the accuracy of the orbit determination and prediction of the small space debris objects. This is one of the key research objectives for RP3 and excellent progress was achieved through this international collaboration.

Additional international linkages with non SERC participants have occurred with the Korea Astronomy and Space Science Institute (KASI). A meeting was held in Daejeon, South Korea between SERC researchers and KASI representatives. This was very productive in discussing measurement and modelling of non-gravitational perturbation of spin dynamics of artificial satellites. This research will help to understand the spin dynamics of defunct geostationary (GEO) satellites placed on the graveyard orbit to explain why those objects gain rotational energy and speed up over time. SERC also hosted a delegation from KASI when they visited Australia in May 2015.

In addition, SERC has developed external linkages with non-Participant Universities in Australia to facilitate sourcing the most promising students for scholarship opportunities. Currently this non-participant university collaboration includes the University of Queensland and the University of Sydney but will be expanded in the next reporting period.



*Figure 16: NICT 1.5m telescope in Tokyo, Japan, used for SERC research*

## 4.4 Financial Management

SERC has implemented management processes and cost controls in an aggressive attempt to limit all CRC administrative costs to around 25% (\$1 million annually) of all available cash over the CRC funding period. This will allow over 70% of all cash funds to flow to research and education programs.

Key financial achievements for the reporting period include:

- Outsourcing financial management and reporting, providing cost savings while providing access to a broad professional skill base. SERC controls cash and payments.
- Appointing a SERC Finance Officer to disburse cash and undertake finance tasks including accounts payable and receivable.
- Establishment of bank accounts with Westpac Banking Corporation.
- Development and implementation of rigorous financial management policies, procedures and guidelines including flow charts, in-kind assessments and delegations of authority.

No significant issues with respect to financial management were experienced during the reporting period.

### Funds Carried Forward

SERC carried forward \$2.25 million in (largely) uncommitted cash at 30 June 2015. In addition around \$0.3 million of cash was carried forward by RMIT from SERC advance payments. This effectively created a \$2.6 million carry forward for SERC.

The temporary excess in cash is caused by the slower-than-expected recruitment in Research Programs which significantly slowed staff outgoings and placement of equipment orders.

Recruitment has now accelerated and future budgets will reduce the cash carry forward to a minimum appropriate operational amount over three years.

### Administrative Costs

SERC has overshot its objectives in cost saving in administration and management, with increases of expenditure now required to ensure

appropriate resources. This planned expansion of administrative staff, to include a full-time research director, will not impact the goal of preserving more than 70% of all SERC cash for research and education programs.

### Travel

SERC has had extremely low travel costs, due to its slow build-up of technical meetings, workshops and symposia. Also, much international liaison was deferred pending the establishment of momentum in the Research Programs.

These restrictions will be removed in the 2015/16 fiscal year, and appropriate relevant travel will be undertaken.

### Key Changes from 2014

SERC is tracking very close to its original and aggressively lean cash flow plans. The key change in 2015 is the allocation of reserves to the Research Programs in accordance with recommendations from the annual review by the Research Management Committee.

Based on the current review of SERC research, most of these reserves will be deployed to increase the probability of success for the debris manoeuvre experiment.

### Summary

SERC now has sufficient data on its financial operations and obligations to begin deploying its cash reserves towards its Research Programs, guided by the research review. At the same time a small increase in SERC administrative and travel costs will be allowed to establish enhanced program management, coordination and liaison.

SERC cash reserves will be progressively run down to the minimum appropriate operational amount over three years through this process of review and re-allocation. At 30 June 2016 the cash reserve will be reduced to less than \$1.9 million.

### Participant Cash Contributions

For the reporting period, SERC received 100% of Participant cash contributions: \$380,000.

### Participant In-kind Contributions

In 2014-15 SERC participants provided staff in-kind contributions to a total of 10.1 FTE, with non-staff in-kind contributions totalling \$3.4 million. The total of in-kind contributions was within 10% of agreement commitments and, considering the slow start to resource consumption and the currently-accelerating pace, SERC expects in-kind contributions to closely match commitments across the term of the CRC.

### Financial Statements

SERC financial statements have been prepared as general purpose accounts in accordance with the Commonwealth Government reporting requirements for CRCs and Australian Accounting Standards. The SERC Financial Report will be submitted to the ACNC in December 2015 as required.



Figure 17: SERC CEO, Dr Ben Greene, giving a tour of Mt Stromlo facilities

## 5.0 Other Activities

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

## 6.0 Additional Requirements

### 6.1 External Reviews

#### First Year Review

The SERC first year review was scheduled to take place on Thursday 28 May 2015. Given the closeness in time between the date set for SERC's first annual review and the release of the Miles Review Report on the CRC Programme,

"Growth through Innovation and Collaboration", the Department decided to postpone the external SERC first year review.

At the time of writing this Annual Report, a date for the SERC first year review has not been advised by the Department.

### 6.2 Internal Reviews

#### First Quarter Review of Research Programs

An internal review of each Research Program was conducted by SERC in September 2014 to assess progress to date and to refine the objectives, budgets and milestones for each Research Program going forward.



Following the review, research contracts were awarded to Essential Participants to execute two of the SERC Research Programs. The management contracts negotiated with these Participants result in lower costs, appropriate accountability and a sharper focus on research delivery outcomes.

#### First Year Review of Research Programs

The first internal annual review of SERC Research Programs commenced in May 2015.

The review is being conducted by a Research Management Committee working group led by Dr Ben Greene (Chair) and involves the four SERC Research Program Leaders. The SERC Research Program review process is outlined in Figure 18.

A full copy of the SERC Research Program Review and recommendations will be submitted to the Department of Industry, Innovation and Science in November 2015.

### SERC Annual Research Program Review Process

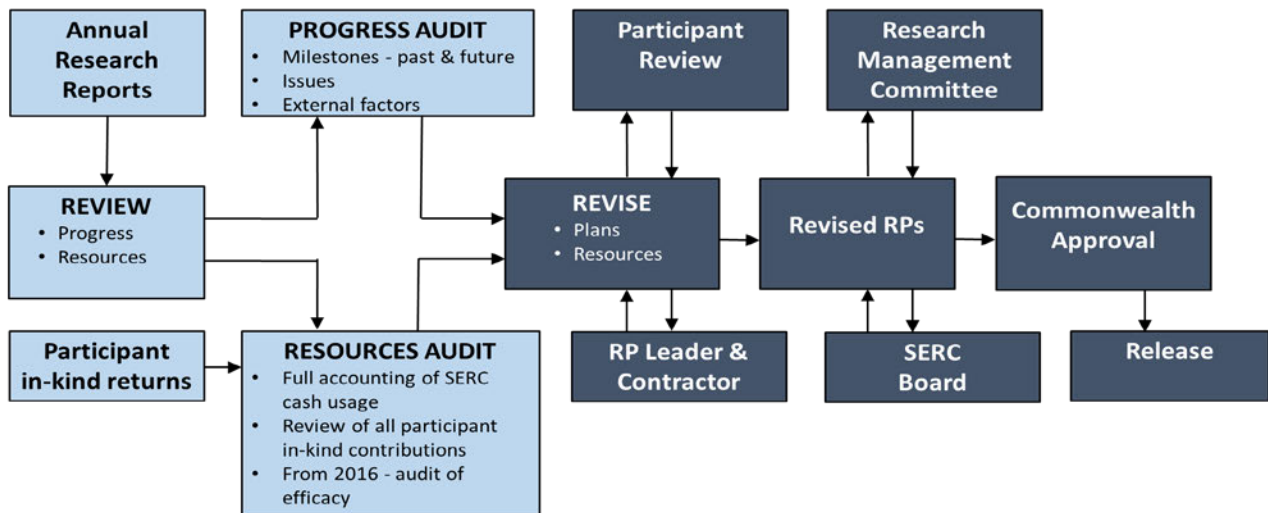


Figure 18: The SERC Annual Research Program Review Process



## 7.0 Glossary of Terms

*Table 15: Glossary of terms included in this report*

Term	Definition
ACNC	Australian Charities and Not-for-profits Commission
ANU	The Australian National University
Adaptive Optics (AO)	Adaptive Optics is 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.
Centre IP	Refers to IP held by SERC
Colloquium	An academic conference or seminar
CRC	Cooperative Research Centre
CW	Continuous wave laser refers to a laser that produces a continuous output beam.
EIPT	Economic Impact Performance Tool (round 11 onwards)
EOSSS	EOS Space Systems Pty Ltd
EOS	Electro Optic Systems Pty Ltd
GEO	Geostationary earth orbit
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.
GRACE satellites	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.
HF signal paths	Refers to signal paths from high frequency satellites.
IP	Intellectual property
KASI	Korea Astronomy and Space Science Institute
LMC	Lockheed Martin Space Systems Company
NASA	The National Aeronautics and Space Administration (NASA) is the United States government agency responsible for the civilian space program as well as aeronautics and aerospace research.
NICT	The National Institute of Information and Communications Technology (Japan)
OPTUS	OPTUS Satellite Systems
ResMC	Research Management Committee
RMIT	RMIT University
RP	Research Program
SERC	Space Environment Research Centre
SGP4	Refers to the "Simplified General Perturbations-4" analytical propagation model that is used to calculate the positions of space debris relative to earth using a two-line element (TLE).
SME	Small to medium enterprise
SOCRATES	Refers to the Satellite Orbital Conjunction Reports Assessing Threatening Encounters in Space service which provides information on conjunctions.
SSA	Space situational awareness is the ability to accurately characterise the space environment and activities in space.
TLE	Two-line element data, a format for distributing orbital elements data.

## Appendix 1 – 2014-15 Publications and Presentations

### Formal Publications

Table 16: Formal publications produced during 2014-15

Date	Title	Published in / Presented at	Lead Author	Other Authors	Publication type
2014	Achievable debris orbit prediction accuracy using laser ranging data from a single station	Advances in Space Research, 54(1), pp. 119-124	J. Sang	J. C. Bennett	Scholarly refereed journal article
2014	Coherent beam combining using a 2D internally sensed optical phased array	Applied Optics	Lyle E. Roberts	R. L. Ward R. Fleddermann D. A. Shaddock	Scholarly refereed journal article
2014	Experimental results of debris orbit predictions using sparse tracking data from Mt Stromlo	Acta Astronautica, 102, pp. 258-268.	J. Sang	J. C. Bennett	Scholarly refereed journal article
2014	Geomagnetic control of equatorial plasma bubble activity modelled by the TIEGCM with Kp	Geophysical Research Letters	B. A. Carter	K. Zhang R. Norman	Scholarly refereed journal article
2014	Space situational awareness – protecting assets in space from orbital debris (a RMIT University perspective on the Space Environment Management CRC)	Geospatial Science Research	K. Zhang	J. C. Bennett C. H. Smith B. Greene J. Sang B. A. Carter R. Norman Y. Zhao S. Wu	Refereed conference paper
2014	Space Situational Awareness – protecting assets in space from orbital debris (a RMIT University perspective on the Space Environment Management CRC)	In: C. Arrowsmith, C. Bellman, W. Cartwright and M. Shortis (eds.), Proceedings of the Geospatial Science Research 3 (GSR_3), Germany, 2–3 Dec 2014, pp. 1–8.	K. Zhang	J. C. Bennett C. H. Smith B. Greene B. A. Carter R. Norman Y. Zhao S. Wu	Refereed conference paper
2014	The Australian Space Research Program Project: Platform Technologies for Space Atmosphere and Climate: Progress and Preliminary Results	International Association of Geodesy Symposia, 139 (CPCI-S indexed), Springer-Verlag, pp. 19-25, ISBN: 9783642372216	K. Zhang	J. C. Bennett B. A. Carter R. Norman S. Wu	Book chapter
2014	Using solar wind data to predict daily GPS scintillation occurrence in the African and Asian low-latitude regions	Geophysical Research Letters	B. A. Carter	K. Zhang R. Norman	Scholarly refereed journal article



Date	Title	Published in / Presented at	Lead Author	Other Authors	Publication type
2014	Weak-light phase tracking with a low cycle slip rate	Optics Letters	Samuel P. Francis	R. L. Ward D. A. Shaddock	Scholarly refereed journal article
2015	An analysis of very short-arc orbit determination for low-earth objects using sparse optical and laser tracking data	Advances in Space Research, 55(2), pp. 617-629.	J. C. Bennett	C. H. Smith K. Zhang	Scholarly refereed journal article
2015	Dynamic statistical optimization of GNSS radio occultation bending angles: an advanced algorithm and its performance analysis	Atmospheric Measurement Techniques	Y. Li	G. Kirchengast B. Scherllin-Pirscher R. Norman Y. B. Yuan J. Fritzer M. Schwaerz K. Zhang	Scholarly refereed journal article
2015	Quantifying residual ionospheric errors in GNSS radio occultation bending angles based on ensembles of profiles from end-to-end simulations	Atmos. Meas. Tech. Discuss	C. Liu	G. Kirchengast K. Zhang R. Norman Y. Li S. Zhang J. Fritzer M. Schwaerz S. Wu Z. Tan	Scholarly refereed journal article
2015	Recent Trends of Satellite Communication Technologies Applied to New Frontiers	Institute of Electronics, Information and Communication Engineers of Japan (IECE) Vol.J97-B, No.11,pp.979-991 (in Japanese)	Naoto Kadowaki	Morio Toyoshima Yasuhi Munemasa	Scholarly refereed journal article
2015	Simulating the impact of refractive transverse gradients resulting from a severe troposphere weather event on GPS signal propagation	IEEE JSTARS	R. Norman	J. Le Marshall W. Rohm B. A. Carter G. Kirchengast S. Alexander C. Liu K. Zhang	Scholarly refereed journal article

## Other Publications and Presentations

Table 17: Other publications and presentations produced during 2014-15

Date	Title	Published in / Presented at	Lead Author	Other Authors	Notes / Impact Factors
2014	A sodium laser guide star facility for the ANU/EOS space debris tracking adaptive optics demonstrator	SPIE on "Adaptive Optics Systems IV", ed. Marchetti, E., Close L. M., Veran, J. IP.	Céline d'Orgeville	Francis Bennet Mark Blundell Francois Rigaut Craig Smith Yue Gao Ami Chan Ian Price Yanjie Wang Ian Ritchie	Conference presentation
2014	Adaptive optics for space debris tracking	SPIE on "Adaptive Optics Systems IV", ed. Marchetti, E., Close L.M., Veran, J.IP.	Francis Bennet	Celine d'Orgeville Francois Rigaut Craig Smith Ian Ritchie Yue Gao Nicolas Paulin Yanjie Wang	Conference presentation
2014	Adaptive optics to enhance tracking of space debris	SPIE newsroom, short news articles	Francis Bennet	Francois Rigaut Ian Ritchie Craig Smith	Conference presentation
2014	An Analysis of Debris Orbit Prediction Accuracy from Short-arc Orbit Determination Using Optical and Laser Tracking Data	Advanced Maui Optical and Space Surveillance Technologies Conference	J. C. Bennett	J. Sang C. H. Smith K. Zhang	Conference paper based on scholarly refereed journal article
2014	An analysis of debris orbit prediction accuracy from short-arc orbit determination using optical and laser tracking data	Advanced Maui Optical and Space Surveillance Technologies Conference, 9 – 12 September, 2014, Maui, Hawaii.	J. C. Bennett	C. H. Smith K. Zhang	Conference presentation
2014	An analysis of debris orbit prediction accuracy from short-arc orbit determination using optical and laser tracking data	Advanced Maui Optical and Space Surveillance Technologies Conference, 9 – 12 September, 2014, Maui, Hawaii.	J. C. Bennett	C. H. Smith K. Zhang	Conference poster presentation
2014	ASRP to CRC - The RMIT SPACE Research Centre and Future PhD Opportunities at RMIT	Workshop: Utilising Existing Australian Space Capability for Future Growth	K. Zhang		Workshop presentation
2014	Atmospheric profiling using GPS Radio Occultation observations over the Australian and Antarctic regions	AGU Fall Meeting	R. Norman	J. Le Marshall B. A. Carter G. Kirchengast S. Alexander C.-S. Wang K. Zhang	Meeting paper



Date	Title	Published in / Presented at	Lead Author	Other Authors	Notes / Impact Factors
2014	Clear Skies with a Chance of Space Debris	MEANJIN	Nicolas Paulin		Literary magazine article
2014	Collaboration between Optical Communication terminal and High precision camera on board micro-satellite using laser from a ground station	Proceedings of the 58 <sup>th</sup> Space and Science Union, (Nagasaki 2014), 3C05, PP.1-6 (in Japanese)	Hiroo Kunimori	Toshihiro Kubooka	Conference paper
2014	CRC SEM - a new horizon of Australian space tracking research	Australian Space Research Conference	K. Zhang		Conference plenary presentation
2014	CRC Space Environment Management	2 <sup>nd</sup> Australian Workshop on Space Situational Awareness, Canberra	C. H. Smith		Conference presentation
2014	Evaluation of a Single Photon Communication and Ranging System on Ground	IEI3CE Technical Report SANE2014-131 pp.19-2,2015 (in Japanese)	Hiroo Kunimori		Report
2014	Game Over for Space Junk?	Café Scientifique, Canberra Alliance Francaise, ANU RSAA	Nicolas Paulin	Francois Rigaut Craig Smith	Meeting paper
2014	GPS Radio Occultation remote sensing for Antarctic atmospheric research	Australian Space Research Conference	S. Alexander	K. Zhang R. Norman	Conference paper
2014	Ground based adaptive optic enhanced LIDAR for space environment management	Australian Institute of Physics Congress I The Art of Physics	Francis Bennet	Céline d'Orgeville Francois Rigaut Craig Smith Yue Gao Ami Chan Ian Price Yanjie Wang Ian Ritchie	Abstract
2014	High Resolution Ranging Experiment using the Time Comparison Equipment	Journal of the NICT (English) Vol. 61 No. 1 pp.129-132	Yasuhiro Takahashi	Hiroo Kunimori Jun Amagai	Journal article
2014	Joint UK-Australian Space Surveillance Target Tracking, Cueing and Sensor Data Fusion Experiment	Advanced Maui Optical and Space Surveillance Technologies Conference, 9 – 12 September, 2014, Maui, Hawaii.	P. Donnelly	J. C. Bennett C. H. Smith I. Ritchie	Conference paper
2014	Manoeuvring space debris for collision avoidance using ground-based lasers	Australian Space Research Conference	J. C. Bennett	C. H. Smith J. Sang K. Zhang	Conference paper

Date	Title	Published in / Presented at	Lead Author	Other Authors	Notes / Impact Factors
2014	Modelling and Predicting the Daily Equatorial Plasma Bubble Activity Using the TIEGCM	AGU Fall Meeting	B. A. Carter	K. Zhang R. Norman	Conference presentation
2014	Orbit Determination Analysis for a Joint UK-Australian Space Surveillance Experiment	Advanced Maui Optical and Space Surveillance Technologies Conference, 9 – 12 September, 2014, Maui, Hawaii.	M. Rutten	J. C. Bennett C. H. Smith I. Ritchie	Conference paper
2014	Overview of the Space Environment Management CRC	Workshop: Utilising Existing Australian Space Capability for Future Growth, Mt Stromlo	C. H. Smith		Colloquium presentation
2014	Recent advances in understanding the drivers of day-to-day variability in the generation of scintillation-causing Equatorial Plasma Bubbles	Australian Space Research Conference	B. A. Carter	K. Zhang R. Norman	Conference paper
2014	Recent Australian Quest of Space Tracking	Space Debris Precision Tracking and Orbit Determination Workshop	K. Zhang		Workshop presentation
2014	Remote Maneuver of Space Debris Using Photon Pressure for Active Collision Avoidance	2014 OSA Optics and Photonics Congress, Canberra	C. H. Smith		Congress presentation
2014	Research Program 1 technical presentation	SERC Participants' Colloquium, Mt Stromlo	C. H. Smith		Colloquium presentation
2014	Severe space weather events and their impact on our technology-dependent society	Australian Space Research Conference	B. A. Carter		Conference presentation
2014	Strategies for Space Geodetic Data Analysis in the Coming GGOS Era	Japan Geoscience Union Regular Meeting 2015 (Makuhari-Messe)	Hiroo Kunitomi	Toshihiro Kubooka	Meeting presentation
2014	Technical Description of Radar and Optical Sensors Contributing to Joint UK-Australian Satellite Tracking, Data-fusion and Cueing Experiment	Advanced Maui Optical and Space Surveillance Technologies Conference, 9 – 12 September, 2014, Maui, Hawaii.	J. Eastment	J. C. Bennett I. Ritchie C. H. Smith	Conference paper
2014	The simulated impact of a severe troposphere weather event on GNSS signal propagation paths	Australian Space Research Conference	R. Norman	K. Zhang J. Le Marshall W. Rohm B. Carter S. Alexander	Conference paper

Date	Title	Published in / Presented at	Lead Author	Other Authors	Notes / Impact Factors
2014	Understanding the Physical Drivers of the Occurrence of Scintillation-Causing Equatorial Plasma Bubbles	Space Environment Applications, Systems, and Operations for National Security	B. A. Carter		Conference paper
2015	A new prediction capability for post-sunset equatorial plasma bubbles	Ionospheric Effects Symposium. Where it won the "Young Scientist Award for Best Paper"	B. A. Carter	K. Zhang R. Norman	Conference paper and presentation.
2015	CRC SEM - a new horizon of Australian space tracking research	1st workshop on Laser Solutions for Orbital Space Debris, Paris 2015	K. Zhang		Workshop presentation
2015	High Earth Orbit Determination Study	Internal Technical Report	J. C. Bennett		Report
2015	Research Program 3: Space Asset Management	SERC Participants' Colloquium	J. C. Bennett	D. Kucharski	Colloquium presentation
2015	Simulated GNSS signal propagation paths during a severe troposphere weather event	The International Union of Geodesy and Geophysics	R. Norman	J. Le Marshall W. Rohm B. Carter S. Wu Y. Yuan K. Zhang	Conference paper



## Appendix 2 – SERC Scholarship Students

*Table 18: SERC PhD students for 2014-15*

Date Commenced with CRC	Student Name	University	Thesis topic	(Expected) completion date	Research Program
1 January 2015	Yang Zhao	RMIT University	Two-line Element data quality control and its application in Space Situational Awareness	April 2018	RP2
5 January 2015	Lyle Roberts	ANU	Internally sensed optical phased array	January 2016	RP4
8 January 2015	Samuel Francis	ANU	Displacement sensing architectures with digital interferometry	December 2016	RP4
5 January 2015	Shasidran Raj	ANU	Coherent laser ranging with CW lasers	June 2017	RP1

*Table 19: SERC undergraduate student for 2014-15*

Date Commenced with CRC	Student Name	University	Research topic	(Expected) completion date	Research Program
5 January 2015	Anna Zovaro	University of Sydney	Test of the LGS beam pointing mirror	November 2015	RP1 and RP4