Lighting Up Down Under: a Science and Technology Studies examination of policy, legal and organisational challenges encountered during the development of Active Debris Removal technology in Australia

E9.1 A6.8 Political, Legal, Institutional and Economic Aspects of Space Debris Mitigation and Removal - STM Security

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Abstract:

On 8 April 2021, Australian / US company Electro Optic Systems (EOS) announced the development of a guide star laser to track and move space debris. The technology promised to measure in almost real-time the perturbations in the atmosphere, which could then feed through an adaptive optics loop and enable a second laser to deliver a burst of high-power infrared energy direct to an object in low-earth orbit, moving it out of the way of a collision, or pushing it into a lower orbit to re-enter the atmosphere. This dual-use technology was billed as a method of Active Debris Removal (ADR), attracting significant interest in Australia and internationally. It was developed by a Cooperative Research Centre ('CRC') called SERC (Space Environment Research Centre), a type of private-public partnership with a specific structure, funded in part by the Australian Government, and in part by various academic and private entities, between 2014 and 2021. This paper presents a detailed sociological study carried out between 2018 and 2021 of SERC's operations through an STS (Science and Technology Studies) lens.

Although ADR is currently unfeasible at scale, both technologically and legally, this has not prevented continued investment in ADR internationally, presenting growing challenges for international and domestic law. This paper demonstrates how SERC used institutional structures available in Australia to temporarily resolve some of the problems associated with the development of dual-use technology. In particular, it outlines how a diverse range of scientific and industrial interests were brought together and enacted through its specific research, corporate, financial, and social structure. Through a detailed description of SERC's ADR technology (in particular, the guide star laser, adaptive optics system, and high power laser) which combines published materials with first-hand accounts, this paper demonstrates how development was impacted at various points by a combination of technological, legal, and organisational challenges. In doing so, it provides empirical input to ongoing legal and technical conversations about the development of ADR policy, process, and technology, promoting a transdisciplinary approach to the examination of ongoing efforts to improve debris mitigation and removal practices internationally.

Introduction:

On 8 April 2021, in "a real breakthrough for space technology worldwide", Electro Optic Systems (EOS) announced the development of a guide star laser to track and move space debris.[1] The technology promised to measure in almost real-time the perturbations in the atmosphere, which could then feed through an adaptive optics loop and enable a second laser to deliver a burst of high-power infrared energy direct to an object in low-earth orbit, moving it out of the way of a collision, or pushing it into a lower orbit to re-enter the atmosphere; or, as EOS framed it, "the remote manipulation of suitable objects in space".[2] Billed as a solution to the problem of space debris, EOS's announcement confirmed that IP developed in partnership with a range of private and university institutions under the banner of the 'Space Environment Research Centre' (SERC) was now owned by EOS, and ready to be commercialised.[3]

SERC's laser is just one of numerous technological solutions for ADR that have been proposed over the last decade. At the time SERC was operating, alternatives to lasers under consideration internationally included tentacles, robotic arms, nets, tethers, harpoons, lassos, foam, and adhesives.[4] However, it is important to note that even by 2019, when SERC wound up most of their research operations, no method, including lasers, had progressed past the conceptual and early experimental phase.[5] ADR is incredibly technically complicated, whether attempted from space or from Earth. In this paper I illustrate that although ADR is currently unfeasible at scale both technologically and legally, this has not prevented continued investment in ADR internationally, presenting growing challenges for international and domestic law. Importantly, SERC is one example of how organisations could use, and are using, institutional structures to temporarily resolve some of the problems associated with the development of dual-use technology, and to progress ADR research.

The story of how the guide star laser was developed is as much a story of economic, political, legal, and social structures as it is about technology, motivating a Science and Technology Studies (STS) approach. The Space Environment Research Centre (SERC), the banner under which this research was undertaken, began operations in 2014, was gradually wound

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[1] (2021). World-first Laser Developed to Blast Space Junk, Nine News Australia**:** 2:34., 0:26.

[2] (2021). "New Guide Star Laser Technology Developed." Retrieved 14/05/21, from https://www.eos-aus.com/new-guide-star-laser-technology-developed/.

[3] Ibid.

[4] Shan, M., J. Guo and E. Gill (2016). "Review and Comparison of Active Space Debris Capturing and Removal Methods." Progress in Aerospace Sciences **80**: 18-32. p20 and p26

[5] Mark, C. P. and S. Kamath (2019). "Review of Active Space Debris Removal Methods." Space Policy **47**: 194-206. P204

up in 2020, and was formally de-registered in 2021.[6] It arose from a pre-existing research partnership between ANU's Research School of Astronomy and Astrophysics (RSAA) and EOS Space Systems. These two organisations, and others, formed a new structure, a 'Cooperative Research Centre' (CRC) within the Australian science funding policy that existed at the time. A CRC is a type of private-public partnership with a specific structure, funded in part by the Australian Government, and in part by various academic and private entities. Through its specific research, corporate, financial, and social structure a diverse range of scientific and industrial interests were brought together and enacted.

This Australian policy and funding model, brought into Australian national policy in 1991,[7] specifically aims to create industrial-academic hybrids. The CRC program was designed by Chief Scientist Professor Ralph Slatyer,[8] as "the institutionalisation of cross-sector collaboration in R&D".[9] The structure represents a deliberate blurring of the lines between academia and industry which operated "primarily to encourage collaboration in research and development between the private sector and the public sector research bodies but also to address research concentration for world-class teams and [prepare] PhD graduates for non-academic careers".[10] Today, the CRC program sits within the purview of the Australian Government Department of Industry, Science, Energy and Resources.[11] In essence, a CRC brings together one or more research organisations and private sector companies who propose to work together to develop new technologies or methodologies, with significant financial support from the Australian Government.

In technical terms, 'SERC' refers to the company that operated what was officially called the 'CRC for Space Environment Management'.[12] As time went on, however, 'SERC' came to refer not just to the company, but to the CRC as a whole. Rather than insist on an administrative technicality, I shall also use the name 'SERC' to refer to both the company and the CRC, except when the distinction is analytically important.

SERC's stated primary aim — to produce technology that could clean up space debris — was non-military in nature, but the secondary purpose — providing EOS with enhanced laser capabilities — pushed SERC into a zone that could be plausibly termed 'dual-use'. This paper traces in detail the technological, political, social, and financial structures that existed within and around SERC that enabled it to form an organisational 'hyphen' between civil and military space interests in Australia. SERC is an example of how Australia's industry institutionalises the overlaps between military and scientific interests in space. Through an examination of legal and policy issues in conjunction with an explanation of SERC's ADR technology (which included a guide star laser, adaptive optics system, and high power laser) which was developed through a combination of published materials and first-hand accounts, this paper provides empirical input to ongoing legal and technical conversations about the development of ADR policy, process, and technology, promoting a transdisciplinary approach to the examination of ongoing efforts to improve debris mitigation and removal practices internationally.

Background to SERC: history and technological ambitions

On 18 January 2003 a bushfire swept through Canberra and surrounding areas, killing four people and, at Mount Stromlo Observatory, destroying $80 million worth of ANU's astronomy infrastructure.[13] While the 2003 fire was not the first to impact the site,[14] which had been formally established in 1924 and transferred to ANU in 1957,[15] the impact on the

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[6] (2021). Application For Voluntary Deregistration of a Company (6010). Space Environment Research Centre Limited ACN 169 043 467. Documents, Australian Securities and Investments Commission (ASIC).

[7] Turpin, T., R. Woolley and S. Garrett-Jones (2011). "Cross-sector Research Collaboration in Australia: the Cooperative Research Centres Program at the Crossroads." Science & Public Policy **38**(2): 87-97. p. 87.

[8] O'Kane, M. (2008). Collaborating to a Purpose: Review of the Cooperative Research Centres Program. Canberra, Dept. of Innovation, Industry, Science and Research. p. xi.

[9] Turpin, T., R. Woolley and S. Garrett-Jones (2011). "Cross-sector Research Collaboration in Australia: the Cooperative Research Centres Program at the Crossroads." Science & Public Policy **38**(2): 87-97. p. 88.

[10] O'Kane, M. (2008). Collaborating to a Purpose: Review of the Cooperative Research Centres Program. Canberra, Dept. of Innovation, Industry, Science and Research. p. xi.

[11] (2021, 19/05/21). "Cooperative Research Centres." Retrieved 21/05/21, from https://www.industry.gov.au/funding-and-incentives/cooperative-research-centres.

[12] (2015). Annual Report 2014 - 2015, Space Environment Research Centre. p. 7.

[13] le Lievre, K. (2017). 2003 Canberra Bushfires Redefined the Future for Mount Stromlo Observatory. The Sydney Morning Herald. Canberra, Australia.

[14] In 1952, a bushfire burned down the observatory workshop, two storage buildings, and telescope records. Bhathal, R., R. Sutherland and H. Butcher (2014). Mt Stromlo Observatory: From Bush Observatory to the Nobel Prize. Victoria, Australia, CSIRO Publishing. p. 97. See also (2012). "Canberra Bushfire 2003." Australian Disaster Resilience Knowledge Hub Retrieved 27/01/21, from https://knowledge.aidr.org.au/resources/bushfire-canberra-2003/.

[15] Bhathal, R., R. Sutherland and H. Butcher (2014). Mt Stromlo Observatory: From Bush Observatory to the Nobel Prize. Victoria, Australia, CSIRO Publishing. p. 27 and p. 98.

community was profound. The 2003 fire was unprecedented in the scale of physical destruction it caused.[16] In the aftermath of the fires, and amidst disputes with the insurers of the observatory, the Australian Government provided $7.3 million to the ANU Research School of Astronomy and Astrophysics (RSAA) to support rebuilding Mount Stromlo's facilities.[17] Rather than replace all the telescopes and observatories that had been lost in the fires, citing ongoing light pollution issues, RSAA decided to continue a process that had already begun, transitioning astronomical observations to their other observatory at Siding Spring.[18] Meanwhile, at Mount Stromlo, the school began constructing the Advanced Instrumentation and Technology Centre (AITC), a $13.5 million facility that would "house the electrical and mechanical design workshops and laboratories, with a large integration and assembly hall attached".[19]

Later, in 2008, as part of a national strategic response to the Global Financial Crisis (GFC), the Australian Government passed the Nation-building Funds Act 2008, establishing the Education Investment Fund (EIF).[20] ANU RSAA received $88.4 million in funding, which went towards two key projects. The first was the purchase of a 5% stake in the Giant Magellan Telescope Design and Development Phase (GMT-DDP) for $65 million, which built on their initial investment in 2006 of $1 million.[21] The second project funded from the Education Investment Fund grant was $21.4 million to "complete the AITC and to do R&D so as to compete for GMT instrumentation and other engineering projects".[22] This injection of funds from the Australian Government enabled the AITC to purchase instrumentation to fill the buildings that had by then been rebuilt with insurance payments and government funds. EOS received $4.04 million for a 'Space Debris Tracking' project through the Australian Space Research Program (ASRP), a grant program announced in the May 2009 federal Budget.[23] The post-GFC funding that the AITC received led to the Space Debris Tracking Project, funded through the Australian Space Research Program (ASRP), and ultimately the bid for the CRC that became SERC.[24]

EOS Space Systems had been operating at Mount Stromlo since 1997, when a contract was signed between the Australian Surveying and Land Information Group (AUSLIG, then sitting within the Commonwealth Department of Industry, Science and Tourism),[25] and EOS to construct and operate a new satellite laser ranging system on the site.[26] Satellite laser ranging refers to the practice of tracking satellites in orbit by bouncing a laser off their reflective surface in order to accurately measure their movement. This facility was among those rebuilt after the 2003 bushfires,[27] and continues to be operated by EOS Space Systems. In 2000, EOS Space Systems demonstrated that they could use a laser to track not only satellites (which were generally made purposefully reflective to make them easier to track), but also space debris, which is an uncooperative target.[28] Previously, space debris tracking had to be done using radar, which was less accurate.[29] In 2010, EOS reported that they had "entered into collaboration" with ANU "for the joint development of their respective AO [Adaptive Optics] capabilities specifically to meet the requirements of Giant Magellan Telescope (GMT) and similar large telescopes".[30] The collaboration had commercial goals, as well as scientific ones: the report goes on to note that "in addition to its GMT and other commercial applications, the AO technology will enhance the effectiveness of deployable EOS space surveillance systems".[31]

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[16] The 2003 fire destroyed not only the workshop, but also "the heritage Commonwealth Solar Observatory Building, where the library and administration staff was housed, all observing facilities, and several homes on Mount Stromlo". (2003). Annual Report 2003, ANU Research School of Astronomy & Astrophysics. p. 2.

[17] Bhathal, R., R. Sutherland and H. Butcher (2014). Mt Stromlo Observatory: From Bush Observatory to the Nobel Prize. Victoria, Australia, CSIRO Publishing. p. 229.

[18] (2005). Annual Report 2005, ANU Research School of Astronomy & Astrophysics. p. 66.

[19] Ibid. p. 66.

[20] (2015). "Education Investment Fund." Australian Government Department of Education, Skills and Employment Retrieved 27/01/2021, from https://web.archive.org/web/20210221084210/https://www.education.gov.au/education-investment-fund.

[21] Bhathal, R., R. Sutherland and H. Butcher (2014). Mt Stromlo Observatory: From Bush Observatory to the Nobel Prize. Victoria, Australia, CSIRO Publishing. p. 319.

[22] Ibid. p. 267.

[23] Biddington, B. (2019). Space Security in the 21st Century: Roles, responsibilities and opportunities for Australia. pp. 160-161.

[24] Ibid. p. 162. In their history of Mount Stromlo, astronomers Bhathal (Western Sydney University) and Sutherland and Butcher (ANU) likewise draw a link between this round of funding and development of a collaborative effort between ANU RSAA and EOS Space Systems on "Space Debris Detection and Monitoring Systems". Bhathal, R., R. Sutherland and H. Butcher (2014). Mt Stromlo Observatory: From Bush Observatory to the Nobel Prize. Victoria, Australia, CSIRO Publishing. p. 269.

[25] (1998). Customer Service Charter. Australian Surveying & Land Information Group. P. Holland.

[26] Moore (2014). History of Satellite Laser Ranging in Australia. 19th International Workshop on Laser Ranging, Annapolis, MD.

[27] Ibid.

[28] (2018). With EOS We're Working with Business and Satellite Technology. Research Stories, ANU Research School of Astronomy and Astrophysics.

[29] Ibid.

[30] (2010). Annual Report 2010, Electro Optic Systems. p. 4.

[31] Ibid. p. 4.

Making good on the promise of this last goal, improving effectiveness of deployable EOS space surveillance systems, a group of research scientists from ANU's RSAA published a paper in collaboration with a team of researchers from EOS Space Systems in 2012 titled 'Adaptive Optics for Laser Space Debris Removal'.[32] The paper characterises space debris as a threat to orbital activities, stating that a "reliable and cost effective method for detecting and preventing collisions between orbital objects is required to prevent an exponential growth in the number of debris objects".[33] It describes the development of an Adaptive Optics Demonstrator (AOD) to "improve the ranging and tracking ability" of the current laser tracking and ranging system operated by EOS Space Systems, "a pulsed laser operating at 1064 nm with 200 W average power", "propagated through the a [sic] 1.8[-metre] telescope located on Mount Stromlo in Canberra, Australia".[34] Notably, this paper explicitly steps beyond discussion of measures that would improve existing passive tracking technology, and proposes using this same technology to conduct "laser ablation",[35] to "modify the orbit of space debris using a ground based adaptive optics (AO) corrected laser".[36] The same atmospheric perturbations that disrupted the wavefronts of light travelling from space to earth would also disrupt the wavefronts of a laser beam travelling from earth to space, weakening its effect on any object. By applying adaptive optics, thereby quantifying and cancelling out these atmospheric effects, researchers hoped that their "corrected laser" could exert a measurable effect on a space object.

Aside from being a useful method for tracking and managing debris, laser ablation technology also had potential to be of broader commercial benefit to EOS's other operations. A 2009 'EOS Defence Business Update' discusses its "Directed Energy (DE) Systems", which "leverage its proven capabilities delivering laser energy to small targets at extreme distance".[37] Where the Adaptive Optics Demonstrator (AOD) had applied adaptive optics to laser technology to improve the predictive capabilities of debris tracking,[38] the 2009 business update goes further, discussing the possibility of using lasers for "laser ablation", "theatre defence", and "missile defence".[39] The document describes missile defence as using "EOS's long-range laser tracking sensors" to "provide detailed information on missiles and warheads for optimising defensive actions", and theatre defence as "DE (laser) destruction of incoming missiles, artillery and mortar rounds at short range, to protect personnel in operational theatres".[40] In more civil applications, laser ablation is described as a cost effective way of "providing long-range thrust to space objects from earth. This technology can be used for space freight transport and space debris removal".[41] In the 2009 update, EOS reported that they had "used around $25m of project funding, including $10m of Australian Government grants, to complete the research and development phase" of laser ablation technology, and a further $20 million for "scaling up for practical deployment",[42] but that:

> *After initial successes in 2005 and 2006, the company's progress in developing long-range laser ablation systems slowed as it moved to address the engineering issues associated with scaling up the deliverable thrust in space to meet practical requirements.*[43]

Instead of investing further to progress long-range laser capabilities that might have applications for space, EOS instead "leveraged its laser tracking and laser ablation technologies to develop theatre defence and missile defence products with lower capital cost than laser ablation systems".[44] In short, EOS had the technical capability to create a laser ablation system that could work on space objects, but they could not commercially justify spending more time and money on that research without further external investment, so instead they redeployed that technology to enhance their defence capabilities.

Proposing the laser ablation project as a CRC would enable EOS and RSAA to continue to work together on developing technology without an immediate commercial application, supplemented by team members from other institutions and

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[32] Bennet, F., R. Conan, C. D'Orgeville, M. Dawson, N. Paulin, I. Price, F. Rigaut, I. Ritchie, C. Smith and K. Uhlendorf (2012). "Adaptive Optics For Laser Space Debris Removal." Proceedings of SPIE - The International Society for Optical Engineering **8447**: 44.

[33] Ibid. p. 1.

[34] Ibid. pp. 1-2.

[35] Ibid. p. 1.

[36] Ibid. p. 1.; See also Bennet, F., C. D'Orgeville, Y. Gao, W. Gardhouse, N. Paulin, I. Price, F. Rigaut, I. T. Ritchie, C. H. Smith, K. Uhlendorf and Y. Wang (2014). Adaptive optics for space debris tracking, SPIE. **9148:** 1-9.; D'Orgeville, C., F. Bennet, M. Blundell, R. Brister, A. Chan, M. Dawson, Y. Gao, N. Paulin, I. Price, F. Rigaut, I. Ritchie, M. Sellars, C. Smith, K. Uhlendorf and Y. Wang (2014). A Sodium Laser Guide Star Facility for the ANU/EOS Space Debris Tracking Adaptive Optics Demonstrator, SPIE. **9148**.

[37] (2009). EOS Defence Business Update. Canberra, Electro Optic Systems Holdings Limited. p. 2.

[38] Bennet, F., R. Conan, C. D'Orgeville, M. Dawson, N. Paulin, I. Price, F. Rigaut, I. Ritchie, C. Smith and K. Uhlendorf (2012). "Adaptive Optics For Laser Space Debris Removal." Proceedings of SPIE - The International Society for Optical Engineering **8447**: 44. p. 5.

[39] (2009). EOS Defence Business Update. Canberra, Electro Optic Systems Holdings Limited. p. 2.

[40] Ibid. p. 2.

[41] Ibid. p. 2.

[42] Ibid. p. 3.

[43] Ibid. p. 2.

[44] Ibid. p. 3.

with federal government support. The CRC would produce an adaptive optics system for a high power laser to track space objects, bringing together instrumentation and prediction technologies. Crucially, it would formalise collaboration that was already occurring. Yet despite a track record of successful collaboration at Mount Stromlo, the CRC was initially knocked back. The team removed all references to classified research and pitched it again. This time, they were successful. With funding secured, the CRC's Board of Directors was formed in April 2014,[45] and CRC opened as the Space Environment Research Centre (SERC) on 1 July 2014.[46]

Key to SERC's branding, mandate, and operations was the way in which the team actively shaped the narrative. In surrounding media, space debris was framed as an environmental and commercial threat, and SERC as a viable solution to a pressing issue; an "environmental problem", a type of orbital pollution, "kind of like the way we've polluted oceans and rivers".[47] Importantly, SERC was positioned from the start as a civil, non-military, undertaking.

At the formation of the CRC, each of the participants signed agreements which were customised depending on the level of their planned involvement and their specific regulatory requirements. The agreements included schedules which specified research milestones, as well as in-kind and financial contributions. While the CRC was not intended to work on classified material, there were still complexities associated with international involvement in a uniquely Australian research structure, which required bespoke solutions, and there was a gap of six months between the signing of the Commonwealth Agreement in June 2014 and the execution of the 'Other Participants' agreements, which was not completed until December 2014.[48]

In their first Annual Report, SERC published a short paragraph that outlined the reasons that each institution had chosen to be involved. In addition to ANU, RMIT SPACE Research Centre joined as a University Participant, contributing their "considerable expertise in developing models for reliably propagating or forecasting orbits in the variable space environment",[49] which had been proven in the preceding ASRP collaboration. Optus Satellite Systems, registered as an End User Industry Participant, stated an interest in monitoring their $8 billion telecommunications infrastructure for debris risk.[50] Lockheed Martin Space Systems USA was classed as "both a potential user and potential service provider for space environment management services", offering SERC their technology, skills, and "domain knowledge".[51] The report also lists the University of Arizona and OAW IWF (The Space Research Institute in Graz, Austria) as additional 'Partners' with whom Memoranda of Understanding had been signed.[52]

Over the course of 2014, SERC went from being an idea pitched to a government committee, to a fully funded, operational Australian Public Company, complete with headquarters, reporting requirements, staff, governance structures, and a social media presence. This step, at which ideas crystalised into existence, forcing decisions about branding, language, and other symbolic elements, condensed the imaginings of SERC into an entity that itself had agency. SERC took on an "identity",[53] independent of ANU, EOS, or any other participant or creator.

By the time SERC was launched on 2 December 2014 at Parliament House by the Honourable Ian Macfarlane MP,[54] it already had momentum. The official launch event was attended by more than 60 guests who were treated to media interviews, a "ceremonial signing" of the NICT Participant Agreement, and tours of the scientific facilities at Mount Stromlo.[55] SERC was not just a scientific partnership: it was a diplomatic event, and the guests included representatives from the US and Japanese Embassies and from the Australian Government, as well as from science and industry.[56]

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[45] (2015). Annual Report 2014 - 2015, Space Environment Research Centre. p. 7, p. 29.

[46] Ibid. p. 7.

[47] Smith, C. and C. Kimball (2014). New Australian Research Centre to Remove Space Junk, Save Satellites and Spacecraft. ABC News, ABC. For more on space debris as heritage, see Gorman, A. (2005). The Archaeology of Orbital Space. Melbourne, RMIT University. p. 17. For an analysis of space debris in the context of the Anthropocene, see Olson, V. and L. Messeri (2015). "Beyond the Anthropocene: Un-Earthing an Epoch." Environment and Society **6**(1): 28-47. For a history of the conceptualisation of space as an environment, see Rand, L. R. (2016). Orbital Decay: Space junk and the environmental history of Earth's planetary borderlands. 10191526 Ph.D., University of Pennsylvania. pp. 27-28.

[48] (2015). Annual Report 2014 - 2015, Space Environment Research Centre. p. 7.

[49] (2016). Annual Report 2015 - 2016, Space Environment Research Centre. p. 53.

[50] Ibid. p. 54.

[51] Ibid. p. 54.

[52] Ibid. p. 55.

[53] (2015). Annual Report 2014 - 2015, Space Environment Research Centre. p. 26.

[54] Ibid. p. 26.

[55] Ibid. p. 8.

[56] Ibid. p. 8.

After its rapid creation in late 2014, work began in earnest on SERC's research and technical outputs. When SERC first began operating in 2014, the plan was that the ANU RSAA would provide an adaptive optics system (a "bench") which would interface with a guide star laser provided by EOS.[57] The two institutions would work together in a "collaborative effort that uses expertise from both the ANU and EOS teams".[58]

In an explanation published by members of SERC Research Program 1 in 2018, the team outlined the experimental setup required to exert the sort of photon pressure, or "photon flux" that would be required to cause an object in orbit to move.[59] The experimental supersystem is depicted in Figure 1 and the subsystem diagram in Figure 2. The telescope would use reflected sunlight on a space object — "natural guide star light" — to track it across the sky.[60] Meanwhile, the high power laser would need to be positioned in precisely the right place, taking into account the direction of travel of the object, because when the object crossed the laser's beam it would be travelling at between 7km and 10km per second. The system would employ adaptive optics to adjust for atmospheric turbulence, and ensure that when the laser beam hit the object, the wavefronts were still in line. However, by the time natural guide star (NGS) light had been measured, the information provided on atmospheric turbulence would already be out of date. Therefore, the SERC team planned to point the guide star laser ahead of the high power laser to compensate for the time taken for the photons to return and be measured.[61]

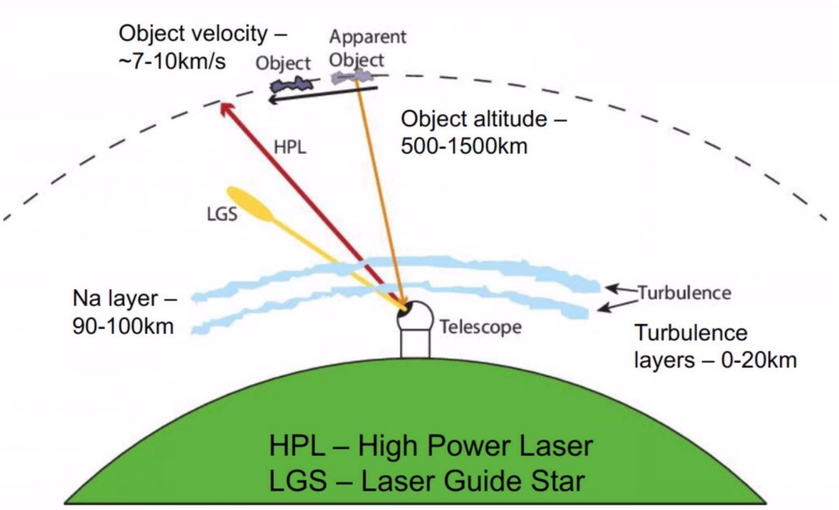

Figure 1 —Diagram of the proposed SERC experiment supersystem showing intended interplay between components. [62]

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[57] D'Orgeville, C., F. Bennet, M. Blundell, R. Brister, A. Chan, M. Dawson, Y. Gao, N. Paulin, I. Price, F. Rigaut, I. Ritchie, M. Sellars, C. Smith, K. Uhlendorf and Y. Wang (2014). A Sodium Laser Guide Star Facility for the ANU/EOS Space Debris Tracking Adaptive Optics Demonstrator, SPIE. **9148**. p. 1.

[58] Ibid. p. 1.

[59] Lingham, M., D. Grosse, F. Bennet, M. Blundell, A. Chan, M. Copeland, C. d'Orgeville, M. Ellis, A. Galla, Y. Gao, L. Gers, J. Hart, E. Houston, V. Korkiakoski, I. Price, E. Rees, F. Rigaut, I. Ritchie, C. Smith, T. Travouillon, A. Vaccarella, Y. Wang and J. Webb (2018). Adaptive Optics Tracking and Pushing System for Space Debris Manoeuvre, SPIE. p. 2.

[60] Ibid. p. 2.

[61] Ibid. presentation recording: 6:20-7:45.

[62] Ibid. presentation slide. 8.

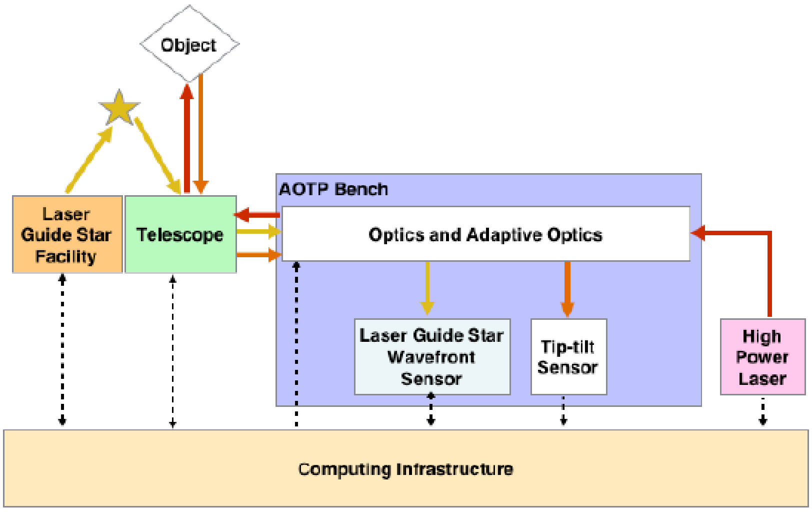

Figure 21 — Subsystem structure of the SERC experimental setup showing interface between the LGS / GSL and the other components. The optical interface is shown in orange, yellow and red, and the software interface is represented by dashed black arrows.[63]

At a purely technical level, the SERC laser guide star facility (LGSF) was made up of three key subsystems, the Beam Combining Optics (BCO), the Beam Transfer Optics (BTO) and the Laser Launch Telescope (LLT),[64] shown in Figure 2 as an orange box and in Figure 3 in detail.[65] The technical purpose of the guide star laser was to create an artificial light source (laser guide star, or 'LGS') by exciting sodium atoms in the atmosphere, from which an accurate reading of atmospheric turbulence could be made.[66] The deformable mirror could then be adapted such that the high power laser beam could be directed with maximum wavefront alignment at the target object (Figure 4).

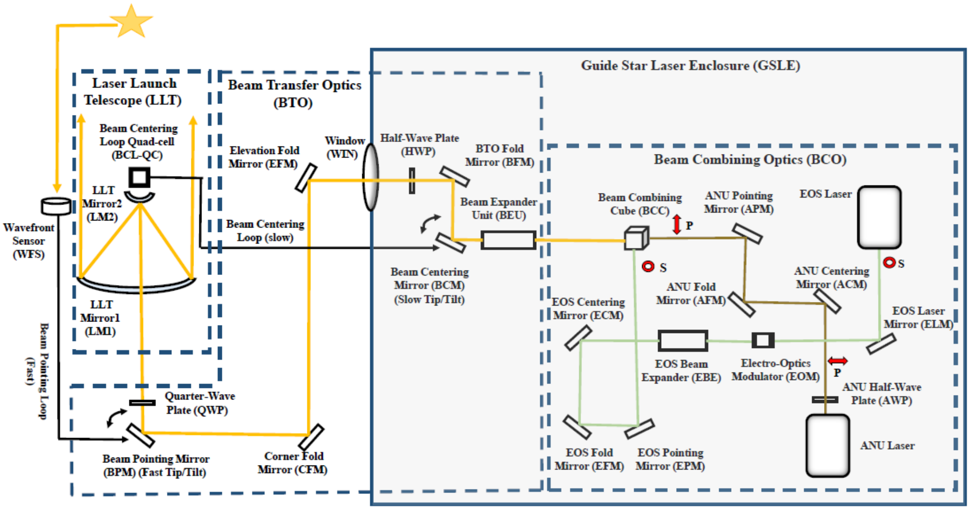

Figure 32 — Diagrammatic representation of the Laser Guide Star Facility.[67]

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[63] Grosse, D., F. Bennet, F. Rigaut, C. d'Orgeville, M. Bold, C. Smith and B. Sheard (2017). Space Debris Manoeuvre with Adaptive Optics Using a Ground-based Telescope. 68th International Astronautical Congress. Adelaide, Australia, International Astronautical Federation (IAF). p. 3.

[64] Martinez, N., C. D'Orgeville, D. Grosse, M. Lingham, J. Webb, M. Copeland, A. Galla, I. Price, W. Schofield, E. Thorn, C. Smith, Y. Gao, Y. Wang, M. Blundell, A. Chan, A. Gray, G. Fetzer and S. Rako (2020). Debris Collision Mitigation from the Ground Using Laser Guide Star Adaptive Optics at Mount Stromlo Observatory. 71st International Astronautical Congress (IAC) – The CyberSpace Edition, International Astronautical Federation (IAF). p. 2.

[65] Ibid. p. 2.

[66] Ibid. p. 2.

[67] Ibid. p. 3.

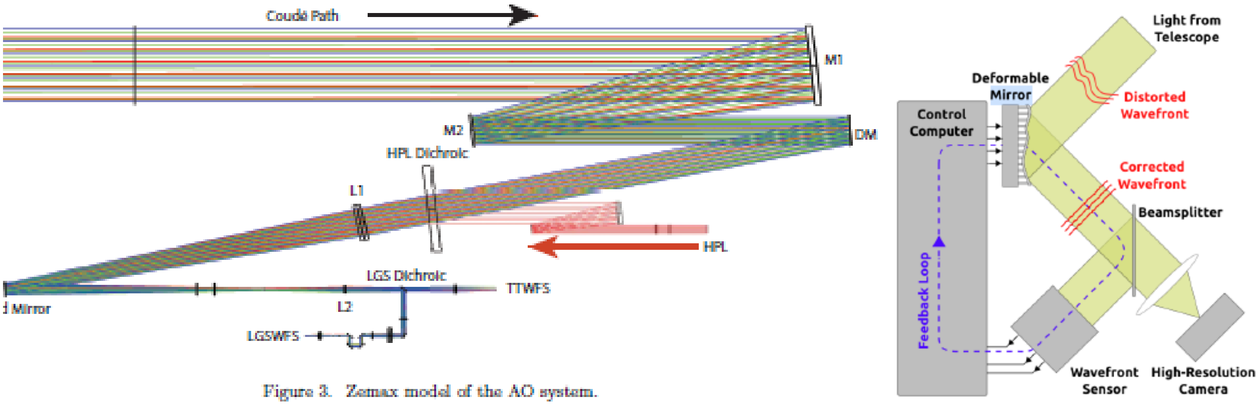

*Figure 4 — **Left**: diagrammatic representation of the path of light from the telescope along the coudé path. 'HPL' stands for 'high power laser', and 'LGS' for 'laser guide star'. 'M2' is the beam expander mirror and 'DM', the deformable mirror, was a larger mirror that physically changed shape in response to inputs from the adaptive optics loop. **Right**: Interface of deformable mirror with the adaptive optics system. The 'control computer' gave instructions to the deformable mirror using a combination of predictions and historical observations.*[68]

There is not scope in this paper to go into depth on the technical setup or the problems encountered in its development,[69] but this brief description provides context for the second part of this paper, which outlines the legal and policy challenges that arise from such activity.

Legal issues

What SERC never openly addressed is that, in addition to being technologically challenging, its laser-push experiment, as originally designed, would have given rise to a range of complex legal issues that have yet to be solved in international law. These issues include liability, responsibility, jurisdiction and control, authorisation and control, and the due regard principle. In the following section I give a brief overview of the legal and political challenges presented by ADR in language that is purposefully accessible to a non-legal reader. I draw an explicit link between the technological dual-use problem and the legal dual-use problem, and outline the entanglements between civil and military interest in ADR technology internationally that complicate efforts to demarcate ADR from space weaponry. I then draw conclusions as to likely implications of international law for SERC, with the proviso that SERC never carried out their ADR experiment, and that there has yet to be a piece of relevant case law in the ADR space generally. While my discussion here is therefore purely academic, it points to the interwoven nature of legal and technical questions, and need to consider them together, particularly in the light of rapid technological development.

The aim of this analysis is to illustrate that the legal frameworks that govern space activities and the political and diplomatic functions which underpin them are, themselves, complex technologies that must be understood and adapted for use in sympathy with scientific and technological development. I draw attention to the fact that SERC used institutional structures that were available in the Australian context and that made it possible to avoid ever having to confront the legal problems posed by the development of ADR technology. This strategy not only went unchallenged, but was in fact encouraged by the Australian Government, and may therefore influence, I would argue, through the creation of state practice, the boundaries of what might be considered to be lawful in future.[70]

My analysis highlights two issues that go beyond SERC's operations. Firstly, there is a gap in domestic and international law regarding the use of ground-based laser ADR that remains open, and that constitutes a potential risk for Australia in the context of its international legal obligations. Secondly, entities like SERC circumvent the awkward impasse that dual-use technologies present for current international legal frameworks by, as I show below, structuring these problems effectively out of existence. Rather than seeking to resolve gaps that arise in existing international law as a result of

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[68] Lingham, M., D. Grosse, F. Bennet, M. Blundell, A. Chan, M. Copeland, C. d'Orgeville, M. Ellis, A. Galla, Y. Gao, L. Gers, J. Hart, E. Houston, V. Korkiakoski, I. Price, E. Rees, F. Rigaut, I. Ritchie, C. Smith, T. Travouillon, A. Vaccarella, Y. Wang and J. Webb (2018). Adaptive Optics Tracking and Pushing System for Space Debris Manoeuvre, SPIE. p. 4.; Copeland, M., F. Bennet, F. Rigaut, V. Korkiakoski, C. D'Orgeville and C. Smith (2018). Adaptive Optics Corrected Imaging for Satellite and Debris Characterisation, SPIE. **10703:** 1-7. p. 2.

[69] Readers who wish to indulge their curiosity on this matter should read Handmer, A. G. (2022). Making a success of 'failure': a Science Studies analysis of PILOT and SERC in the context of Australian space science.

[70] For a clear treatment of the mechanisms and implications of state practice and customary law in the context of international space law, see Cheney, T. E. L. (2020). Sovereignty, Jurisdiction, and Property in Outer Space: Space resources, the outer space treaty, and national legislation. Doctoral thesis, Nothumbria University. pp. 66-103.

technological development (whether such gaps are best considered silences or *lacunae*), SERC's treatment capitalised on the resulting ambiguity, for both the purpose, and with the effect, of facilitating continued investment in, and development of, dual-use technology.[71] My empirical analysis therefore contributes to international legal discourse on ADR development by grounding theoretical discussion in a study of current practice, and establishing stakes for ongoing development of this emerging field of law.

The riddle of space debris is that while everybody agrees on the pressing nature of the issue, there is currently no feasible technical or legal solution that enables its removal while managing the political sensitivities of dual-use activities. Thus, Joan Johnson-Freese, a renowned contributor to academic and policy debates on space and national security, writes, "while it is technically possible to do something about the debris congestion that the United States and other countries profess concern about, the politics of fear, inertia, and delay will likely prevail in the interim".[72] What Johnson-Freese points to here is the problem that sits at the heart of the dual-use dilemma: any technology that is capable of removing debris from orbit for peaceful purposes is likewise capable of interfering with active satellites for non-peaceful purposes. Phipps, a researcher who worked on Project ORION in the 1990s, likewise noted in 2014 that the greatest challenge for laser debris removal (and, I would add, for any ADR method) "is not technical, but political".[73] He wrote:

> *Designing, building and operating a LODR [Laser-Optical Debris Removal] system will require international cooperation to apply the best ideas, as well as to avoid concerns that it is actually a weapon system. Also, cooperation in its operation will be needed to get permission for its use to remove specific debris objects.*[74]

Overarching policy statements made about the similarity between weapons technology and ADR technology almost always seem to maintain the idea that the two are distinct at a technological level, and that the key is finding a demarcation tool which can then be defined and enacted as a control mechanism through international law — an idea that proves to be a fiction, at least in the case of high power lasers like SERC's.

As space lawyers Christopher Newman, Ralph Dinsley and William Ralston have noted, there is a tension between the emphasis placed by the Outer Space Treaty on peaceful uses of outer space and the dual-use nature of ADR technologies that is not resolved in existing space law.[75] The gap between existing international space law and ADR technologies, which space lawyer P. J. Blount classifies as a *lacuna*,[76] has its basis in the difficulty that exists in delineating and legislating the point at which the hyphen falls between 'military-civil'. Efforts to date in international law to define 'space weapon' — for example, through the Prevention of an Arms Race in Outer Space (PAROS) process — have been unsuccessful.[77] In 2014 members of the Space Generation Advisory Council (SGAC), an international non-governmental, not-for-profit organisation which was formed in 1999 to support the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS), "through raising awareness and exchange of fresh ideas by youth",[78] considered the riddle of space debris in the contemporary geopolitical climate. The authors of the paper proposed a 'scorecard' against which potential methods of debris removal could be assessed for their legal, economic, policy, and technical viability.[79] They identified necessary actions such as agreement on a "shared definition of Space debris",[80] but were unable to identify a viable ADR option.

It is hard to think of a space technology that could not in some way be used as a weapon, and what my empirical study of SERC's ADR technology makes apparent is that, at least in this case, there is no way of drawing a line between the two, because there is no difference at a fundamental, technological level. The very same major piece of equipment, a 10kW laser at the core of SERC's project, started life as an enhanced military tracking system within a war machine before

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[71] Opinions differ on whether this gap is a 'silence' or a 'lacuna'. Cheney makes a convincing argument for the treatment of 'gaps' as 'silences' in ibid. pp. 57-61. P. J. Blount, on the other hand, argues that this gap constitutes a lacuna. Blount, P. J. (2019). On-Orbit Servicing and Active Debris Removal: Legal Aspects. Promoting Productive Cooperation Between Space Lawyers and Engineers. P. Anja Nakarada and T. Matteo. Hershey, PA, USA, IGI Global**:** 179-192. p. 180.

[72] Johnson-Freese appears to be talking in theoretical terms here, since ADR has yet to be successfully demonstrated. Johnson-Freese, J. (2016). Space Warfare in the 21st Century: Arming the Heavens, Taylor & Francis. pp. 30-31.

[73] Phipps, C. R. (2014). "A Laser-optical System to Re-enter or Lower Low Earth Orbit Space Debris." Acta Astronautica **93**: 418-429. p. 428.

[74] Ibid. p. 428.

[75] Newman, C., R. Dinsley and W. Ralston (2021). "Introducing the Law Games: Predicting legal liability and fault in satellite operations." Advances in Space Research **67**(11): 3785-3792. p. 3787. See also Froehlich, A. (2019). Space Security and Legal Aspects of Active Debris Removal, Springer International Publishing.

[76] Blount, P. J. (2019). On-Orbit Servicing and Active Debris Removal: Legal Aspects. Promoting Productive Cooperation Between Space Lawyers and Engineers. P. Anja Nakarada and T. Matteo. Hershey, PA, USA, IGI Global**:** 179-192. p. 180.

[77] Ibid. p. 182

[78] (2018, 2021). "About SGAC." Retrieved 07/04/21, from https://spacegeneration.org/about.

[79] Emanuelli, M., G. Federico, J. Loughman, D. Prasad, T. Chow and M. Rathnasabapathy (2014). "Conceptualizing an Economically, Legally, and Politically Viable Active Debris Removal Option." Acta Astronautica **104**(1): 197-205. P. 202

[80] Ibid. p. 200

being proposed to be operated as a civil, environmentally responsible ADR facility. This is not to say that the ADR system that SERC and its partners were working to develop was *itself* a weapon — on the contrary, it was explicitly an unclassified project which aimed to develop a piece of technology for civil applications. But while international attempts to regulate the dual-use problem through technological demarcation have necessarily reached an impasse, organisations such as SERC are, in the meantime, taking advantage of ambiguity and are pressing ahead with the development of dual-use technology. SERC is just one example of how, in the context of the Australian space research sector, organisational structures were used to sidestep legal and moral questions while facilitating the development of military-applicable IP.

Looking internationally, we find comparable structures to SERC's: while marketing materials and funding proposals might claim that these ADR ventures are motivated by environmental concern, those funding ADR research clearly have interests in their dual-use applications too. For example, RemoveDEBRIS, an ADR project led by the University of Surrey became in 2018 "the first mission to successfully demonstrate, in-orbit, a series of technologies that can be used for the active removal of space debris".[81] The mission was deployed from the ISS and consisted of a "mothercraft" mini satellite and two CubeSats that became faux-debris,[82] on which a net and imaging / observation technology were tested.[83] The mothercraft also deployed a harpoon and a target, and included a dragsail.[84] The €15 million project was sponsored by €7 million from the European Commission with the "remainder self-sponsored by the partners".[85] Among the partners is Airbus, whose technological contributions to the project, delivered via its subsidiary 'Surrey Satellite Technology Limited', include the net, the harpoon, and the imaging technology (a "Vision Based Navigation (VBN) system to validate debris-tracking techniques in orbit with cameras and LIDAR").[86] Ultimately, the net successfully wrapped around one of the CubeSats but due to budget restrictions the net was not tethered to the mothercraft, so could not be retrieved or deorbited.[87] The harpoon was also successfully deployed, striking the target "roughly the size of a table-tennis bat",[88] and unlike the net, was tethered to the mothercraft.[89]

The only other ADR method for which on-orbit demonstrations have been commenced at the time of writing is Astroscale's ELSA-d (End-of-Life-Services by Astroscale demonstration).[90] Astroscale is a private company registered in Japan and headquartered in Tokyo,[91] which aims to provide ADR as part of on-orbit servicing.[92] Like SERC and RemoveDEBRIS, Astroscale launched its own target satellite to act as faux-debris, rather than pick a piece of existing debris,[93] thereby avoiding associated legal and political issues. The project plans to use a magnetic system to dock with the target satellite.[94] Astroscale's technology is not yet at a commercially viable point, and in 2019 the company announced that they would be seeking to enter the military marketplace. The managing director of the US subsidiary of the company was quoted in online media platform Breaking Defence as saying:

> *Debris removal is the immediate focus for the company, but there is a lot of [technology] applicability to adjacent areas of the market that end up leading to capabilities that the military needs.*[95]

Like SERC in Australia, the cases of Astroscale and RemoveDEBRIS raise questions about the rhetoric motivating ADR research. To what extent is the persistent interest in developing ADR technology actually due to concern about the growing amounts of debris in orbit, be it commercially motivated, or in terms of the 'space environment'? Or does the framing that ADR research provides offer a convenient language for government and industry actors alike to talk about dual-use technologies without ever having to mention the 'other use' — while also funding and developing military-applicable capability? Is the space industry internationally, and in Australia, using ambiguous language to speak

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[81] Aglietti, G. S., B. Taylor, S. Fellowes, S. Ainley, D. Tye, C. Cox, A. Zarkesh, A. Mafficini, N. Vinkoff, K. Bashford, T. Salmon, I. Retat, C. Burgess, A. Hall, T. Chabot, K. Kanani, A. Pisseloup, C. Bernal, F. Chaumette, A. Pollini and W. H. Steyn (2019). "RemoveDEBRIS: An in-orbit demonstration of technologies for the removal of space debris." The Aeronautical Journal **124**(1271): 1-23. P2

[82] Ibid. p4

[83] Ibid. p4

[84] Ibid. p4

[85] Ibid. p5

[86] (2019). "Testing Technology to Clear Out Space Junk." RemoveDEBRIS Retrieved 09/04/21, from https://www.airbus.com/space/space-infrastructures/removedebris.html.

[87] Aglietti, G. S., B. Taylor, S. Fellowes, S. Ainley, D. Tye, C. Cox, A. Zarkesh, A. Mafficini, N. Vinkoff, K. Bashford, T. Salmon, I. Retat, C. Burgess, A. Hall, T. Chabot, K. Kanani, A. Pisseloup, C. Bernal, F. Chaumette, A. Pollini and W. H. Steyn (2019). "RemoveDEBRIS: An in-orbit demonstration of technologies for the removal of space debris." The Aeronautical Journal **124**(1271): 1-23. P12

[88] Ibid. p15

[89] Ibid. p16-17

[90] (2021). Astroscale Celebrates Successful Launch of ELSA-d, Astroscale.

[91] (2018). "Terms & Conditions." Retrieved 09/04/2021, from https://astroscale.com/terms-conditions/.

[92] (2018). "About Astroscale." Retrieved 09/04/2021, from https://astroscale.com/about-astroscale/about/.

[93] (2021). Astroscale Celebrates Successful Launch of ELSA-d, Astroscale.

[94] Ibid.

[95] Hitchens, T. (2019). Astroscale US Targets DoD Sat Servicing Market. Breaking Defense, Breaking Media, Inc.

simultaneously to civil and military interests? Of course, the answer is complicated. There are a diverse range of institutions and individuals who are interested in ADR for an equally diverse range of reasons. But, as projects like SERC show, ADR development enables countries like Australia to engage in state-sponsored development of the workforce, supply chains, and sovereign capabilities that are themselves also 'dual-use'.

Nevertheless, the awkwardness of the overlaps between civil and military knowledge, technology, and applications inherent to ADR presents challenges for efforts to develop dual-use technologies. Such technologies are subject to strict export control regulations, and, beyond the letter of the law, messaging around the development of dual-use technologies has to be carefully managed to avoid prompting diplomatic, economic, or practical responses from other countries. In a valuable in-depth analysis which traces the history of US concern about space debris at an institutional level, space policy advisor Brian Weeden unpacks in detail why dual-use debris-removal technologies are hard, *politically*, to develop at a national level.[96] Despite being technologically unfeasible at the time, he notes that 2010 marked a shift in US policy away from mitigation (reducing new debris) and towards ADR as a preferred solution.[97] He points out that although the US Government included ADR in their 2010 US National Space Policy,[98] they made the decision not to incorporate a formal space debris mitigation plan to go along with the policy. Weeden states that this was likely due to "costs, lack of specific agency responsibility, and political concerns over some of the active removal technologies being similar to space weapons".[99]

Funding from NASA for ADR research (in line with the Policy's recommendation that NASA and the DoD jointly pursue development of ADR technology) petered out in 2014,[100] almost precisely lining up with the moment SERC's people, technologies, funding, structures, and ideas coalesced at Mount Stromlo, Australia. Explaining this funding and policy 'mixed messaging' in the US context, Weeden writes:

> *Space debris was originally a common driver behind much of the interagency interest in STM, but differences emerged between the national security space community and the civil space community as to the priority of the threat posed by space debris, compared to the threat posed by foreign counterspace capabilities.*[101]

SERC encountered the same political challenges identified by Weeden as existing in the US context, but what is interesting is that it managed to solve some of them through careful arrangement of institutional structures. For example, SERC addressed the high cost of ADR development through bringing together, via the unique financial structures made possible by the CRC program, a combination of public and private funding sources. Further, by assigning value to the use of existing resources, personnel, and IP, through the in-kind component of SERC's funding model, SERC was made into a financially viable venture for government, academic, and commercial entities alike. The complex and convoluted CRC conglomerate which effectively outsourced responsibility for development of ADR to the private and academic sectors meant that the Australian Government did not have to make a public, political statement as to whether management of the 'space environment' was a matter for Defence or for one of the civil agencies.

Finally, SERC did something remarkable, which was to hold in balance the political challenge identified by Weeden, Johnson-Freese, and others: that ADR technology looks *an awful lot like* weapons technology. Blount has argued that best practice in the management of commercial ADR technology development is 'signalling' which establishes norms of peaceful use around such technologies.[102] He writes that because ADR technologies have the potential to spark an arms race due to their dual-use nature, "states will need to paint clear policy redlines about the acceptable uses" of ADR technologies "in order to retain the strategic peacefulness of outer space through clear signalling to other states".[103] By explicitly branding itself as civil, and through a combination of organisational structures, research program delineations, and technological processes that foregrounded the scientific and environmental management aspects of SERC's activities, SERC is an example of just this kind of signalling. In this way, Australian researchers developed high power laser ablation technology using a combination of equipment developed in weapons and civil contexts without ever once (as far as I could determine from publicly available information) arousing political tension or diplomatic concern. However, it is the

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[96] Weeden, B. C. (2017). Case Study of the Interagency Process for Making Presidential Policy Decisions on Dual-Use Space Technology: The Global Positioning System and Space Traffic Management, ProQuest Dissertations Publishing.

[97] Ibid. p. 383-385.

[98] Ibid. p. 384.

[99] Ibid. p. 384-385.

[100] Ibid. p. 411.

[101] Ibid. p. 437.

[102] Blount, P. J. (2019). On-Orbit Servicing and Active Debris Removal: Legal Aspects. Promoting Productive Cooperation Between Space Lawyers and Engineers. P. Anja Nakarada and T. Matteo. Hershey, PA, USA, IGI Global: 179-192.

[103] Ibid. p. 182

very fact that SERC managed to achieve all this, not through constructive engagement with international legal frameworks, but through structuring, branding, and careful rhetoric, that may raise serious impediments to future efforts to effectively regulate the development of dual-use ADR technology.

Of course beyond policy and political considerations, ADR development must also reckon with the existence and operation of international and domestic space law. The remainder of this part of the paper steps through the space law that might have applied to SERC, and considers how existing law addresses (or does not address) the issues raised by ADR.

A key difference between SERC's technology and other ADR efforts (including RemoveDEBRIS and Astroscale's ELSA-d) is that where most ADR uses space-based technologies such as claws, harpoons, or nets, SERC aimed to exert an effect on a space object from Earth. The chief problem for any ADR technology, and one reason that current ADR testing is carried out on purpose-launched objects ('fake debris') rather than existing debris, is that international law which governs space activities (to which Australia is a party) maintains that once launched, any space object or component part remains "under the jurisdiction and control of the launching state".[104] Challengingly for SERC, international space law does not distinguish between debris and functioning satellites: both are considered 'space objects'.[105] Any debris targeted by SERC would therefore have fallen within the scope of Article VIII of the Outer Space Treaty 1967, which states that "a State Party to the Treaty on whose registry an object launched into outer space is carried shall retain jurisdiction and control over such object".[106] If SERC executed the experiment on a piece of debris that was a piece of a satellite initially registered by a state party, the state of registry may be able to argue that the laser experiment was interfering with their right (or obligation) to exercise jurisdiction and control over their space object. Even for unregistered objects, principles of international law may give rise to legal grounds for dispute.

Liability is highly relevant for most ADR activities,[107] but due to a technicality specific to SERC's technology (ground-based lasers) it would be unlikely to arise as an issue because it is improbable that the photons exerting action on a space object would themselves be found to constitute a space object. However, and more relevantly, Australia could be held internationally *responsible* for SERC's activities under Article VI of the Outer Space Treaty because although SERC was not a government agency, the law extends to activities carried out by non-governmental entities, and requires "authorization [sic] and continuing supervision" by States Parties of activities in outer space by all non-governmental entities.[108] Thus, Australia would have had an obligation to assure that SERC's activities were compliant with all the provisions of the Outer Space Treaty. Of particular relevance to SERC's plans were the concepts of 'harmful interference' and 'due regard' which arise under Article IX.

Article IX requires that States undertake all activities in space "with due regard to the corresponding interests of all other States Parties to the Treaty", and imposes a positive obligation on States to "undertake appropriate international consultations" prior to carrying out any "activity or experiment" which could "cause potentially harmful interference" with the activities of others.[109] The sort of laser system SERC was developing was designed to be just strong enough to 'nudge' a space object, but not strong enough to cause physical damage. However, if accidentally directed at the wrong object, an ADR laser system could still "damage or degrade optical sensors",[110] a tactic commonly referred to in its application in military or intelligence contexts as 'dazzling'. While the effects of laser dazzling are usually reversible, accidentally doing so could have led to some awkward conversations for SERC executives and for the Australian Government. In the US, use of high-powered lasers (operated by the Department of Defence) is regulated through the Laser Clearing House (LCH), which checks the satellite catalogue to make sure no unintended space objects are in danger from the proposed activity before approving deployment.[111] In Australia, no such procedure exists (at least publicly). If such a procedure did exist, it is unclear whether SERC, as a hybrid organisation that sits outside of Defence, would be captured by such a policy. Nonetheless, it could be argued that the use of a high power laser, if it were to be deployed in such a way that it accidentally hit a satellite other than its intended target, or had a risk of doing so, might prompt an

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[104] Weeden, B. (2011). "Overview of the Legal and Policy Challenges of Orbital Debris Removal." Space Policy **27**(1): 38-43. p. 41.

[105] Ibid. p.40

[106] (1967). Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, October 10, 1967, 610 U.N.T.S. 205.

[107] Ibid. Article VII; (1972). Convention on International Liability for Damage Caused by Space Objects, 29 March 1972, 961 U.N.T.S. 187.

[108] (1967). Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, October 10, 1967, 610 U.N.T.S. 205. Article VI.

[109] Ibid. Article IX.

[110] Weeden, B. (2011). "Overview of the Legal and Policy Challenges of Orbital Debris Removal." Space Policy **27**(1): 38-43. p. 42.

[111] Ibid. p. 42.

international responsibility on the part of Australia to undertake consultations or otherwise demonstrate that due regard had been paid to the corresponding interests of other States.

However, although it was updated in 2018, Australia's domestic space law, both at the time SERC was conducting its activities, and at the time of writing, does not have a requirement for any entity carrying out a ground-based space activity (such as SERC) to apply for authorisation, nor does it have a process by which such authorisation could occur. Importantly, the lack of a licensing regime does not absolve Australia from state-to-state international obligation. International law still applies, and Australia could still have been held internationally responsible for SERC's acts, and could still *be* held internationally responsible for EOS's, if EOS continues with the ADR development program (or other testing of the space laser system). Were such a case to go to court, it is unclear where the legal obligation would be found to reside. EOS could argue that there was no process under domestic law that they were required to follow, while the Commonwealth could argue in counterpoint that SERC should nevertheless have informed the Government of their intentions, or perhaps that SERC had deliberately concealed their intentions.

There have been cases of private companies deliberately contravening international space law, but it remains unclear to what extent it is possible for a State to disavow a national activity in outer space where it was unauthorised. A recent example of unauthorised space activity is the 2018 launch of SwarmBEE satellites by US start up Swarm Technologies, who applied to the US Federal Communications Commission (FCC) in 2017 for a licence to launch microsatellites. The FCC refused Swarm's application because the small size of the satellites would make it difficult to track them from the ground, increasing the risk of a collision and the creation of more space debris in an already crowded orbit. Unable to get domestic approval to launch, Swarm took their satellites offshore, and launched them on an Indian rocket in early 2018. The Swarm case made headlines in late 2018 when the company was fined $900,000. Eventually, the US FCC worked with Swarm to make their operations compliant and issued a licence for additional SwarmBEE launches.[112] Even beyond the outcome, the case was important not only because it represents a clear enactment of the principle that the State of jurisdiction has a responsibility to authorise and continually supervise activities of private companies, but also because it prompted US officials to consider possible defences to arguments of responsibility (and potentially liability). A defence that may have arisen had the case gone to court is that the US Government reasonably attempted to enact their responsibility by denying Swarm permission to launch through the FCC process, and that Swarm then deliberately and knowingly contravened the authority of the US Government by going offshore.

If SERC had deployed their laser resulting in an adverse outcome, such an argument might be one that the Australian Government could consider: that SERC should have sought permission regardless of whether there was a specific process in place, and that their failure to do so could constitute a wilful contravention of the State's authority. On the other hand (and, in my view, the more persuasive argument) SERC could rightly point to the fact that their plans to experiment with laser ADR were approved *and funded* by the Commonwealth, and that their extensive and intensive formal reporting schedule and regular meetings with the Department ought to have been a sufficient indication that they had not miraculously pivoted to non-space activities in the interim. SERC managed to avoid engaging in a fulsome way with matters of international law by taking advantage of both their unique structural status as a government-funded entity and the lack of a requirement under international law. Given that EOS has announced plans to test the laser ablation technology in future,[113] Australia may need to develop an ad hoc (or more fulsome) authorisation and supervision process for the use of high power ground-based space lasers.

Conclusion

Policy and law around space debris continues to develop, and the threat posed by space debris remains real, but for the moment at least, a significant amount of funds for debris characterisation, capture, and removal technologies flow from private and public military interests. SERC marks an important inflection point in the development of Australia's own space-industrial complex. My research illustrates the ways in which one entity in Australia's space industry recently worked

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[112] Madry, S. (2020). Regulations and Treaty Frameworks for Disruptive Space Innovation. Disruptive Space Technologies and Innovations: The Next Chapter. S. Madry, Springer International Publishing: 165-182. pp. 179-180. See also the Beresheet Mission, outlined in: Cheney, T., C. Newman, K. Olsson-Francis, S. Steele, V. Pearson and S. Lee (2020). "Planetary Protection in the New Space Era: Science and Governance." Frontiers in Astronomy and Space Sciences **7**(90).; Johnson, C. D., D. Porras, C. M. Hearsey and S. O'Sullivan (2019). The Curious Case of the Transgressing Tardigrades (part 1). The Space Review, SpaceNews.; Johnson, C. D., D. Porras, C. M. Hearsey, S. O'Sullivan and M. Vidaurri ibid.The Curious Case of the Transgressing Tardigrades (part 2). The Space Review, SpaceNews; Johnson, C. D., D. Porras, C. M. Hearsey, S. O'Sullivan and M. Vidaurri (2019). The Curious Case of the Transgressing Tardigrades (part 3). The Space Review, SpaceNews.

[113] Garman, L. (2021). EOS Unveils New Space Debris Threat Mitigation Laser. SpaceConnect, Momentum Media.; Freeland, S. and A. Handmer (2021). It's Not How Big Your Laser Is, It's How You Use It: Space law is an important part of the fight against space debris. The Conversation Australia.

with and around available institutional structures to progress the development of ADR technology in the absence of clear national and international policy.

SERC's greatest achievement was that it was able to embrace ambiguity to balance tensions and flourish within their bounds. SERC's partnership with Lockheed US allowed it to navigate ITAR regulations and bring a high power laser out to Australia. Its international collaborators (particularly Japan) reduced the risk that SERC would be perceived as a unilateral Australian project to develop threatening technology: instead, SERC was an international, cooperative, scientific effort. The inclusion of participating organisations from across industry and academia, including Optus, a national provider of civil communication services, helped to shape public perception of SERC as a civil partnership, providing a structural bedrock that underpinned and lent credence to the tactical use of language and imagery in media and communications. SERC balanced the 'civil' with the 'national security', satisfying government that funding the project was in the 'national interest'. In essence, SERC was a beautiful chimera: *just enough* of each thing without being *too much* of any one thing.

On the other hand, while flexible (or absent) regulation may encourage innovation, SERC also provides a warning of the risks that could arise where technological development and commercial progress occurs in the responsibility-distribution mechanism that sits in place of clear national policy. A broader risk beyond Australian borders is that in future SERC may be seen as a chapter in Australia's state practice which may in turn normalise the exploitation of ambiguities in international space law. And yet, SERC also demonstrates clearly that Australia currently has the technical capability in industry and academic institutions to develop complex space technologies. There is thus scope to consider how analytical perspectives such as STS, as demonstrated in this paper, may offer value and inform policy development in dual-use technologies, moving Australia towards a cohesive national strategy.

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