Making a success of ‘failure’: a Science Studies analysis of PILOT and SERC in the context of Australian space science

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Declaration

This is to certify that to the best of my knowledge the content of this thesis is my own work. This thesis has not been submitted for any degree or other purposes.

I certify that the intellectual content of this thesis is the product of my own work and that all the assistance received in preparing this thesis and sources have been acknowledged.

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Date: 30/09/2021

This research was conducted with Human Ethics approval: HREC 2020/145

Abstract

This thesis presents an in-depth empirical investigation, based on participant observation, interviews and publicly available materials, of PILOT and SERC, two recent Australian space science projects that were both connected to the problem of space debris. While PILOT's proposal for funding failed, SERC was successfully funded yet failed to reach its initially stated goal of demonstrating the possibility of Active Debris Removal (ADR) using a ground-based high power laser combined with laser guide star adaptive optics. My analysis illustrates that the Australian space science funding and policy environment changed significantly in the brief period between PILOT's unsuccessful proposal and SERC's formation, marking the period of time in which dual-use space capability development was recognised as a political strategic priority. In SERC's case, dual-use technology has been developed through (substantially) publicly funded institutions and by civil scientists. I argue that the current arrangement of policy and funding structures in the Australian space sciences sector facilitates engagement in dual-use technology development in such a way that two outcomes emerge: first, that moral responsibility for the products of such research is institutionally and individually avoided by distributing it 'up the chain' to national governmental entities, and second, that international legal responsibility is likewise avoided at a national level by distributing it 'down the chain' to institutions. I demonstrate how policy and funding conditions in Australia allowed individuals working in, and adjacent to, the space sciences to maintain, unchallenged, the convenient fiction that science is itself amoral and, to some extent, apolitical.

Acknowledgements

In my studies of SERC and PILOT, I have come to appreciate only too well that when it comes to an acknowledgements section, brevity is appealing, but inherently risky.

Nonetheless, there are truly too many people who have contributed to my research efforts to thank individually. Rather than attempt what is impossible to do well, and necessarily to do it poorly, I will instead restrict myself to the following:

First, to those most directly involved in the research process: I thank my PhD supervisor, Daniela Helbig, for her unwavering support, curiosity, and enthusiasm. She has so far put up with my antics for almost a decade, and I hope she will continue to do so for many decades to come. Thanks must also go to my husband Hunter Smith for his patience, his encouragement, and his resolute belief in my abilities, even when I have given up. He has tolerated my presence slightly longer than Daniela, and I'm delighted that mid-way through production of this thesis he even signed legally binding paperwork that suggests he intends to continue to do so.

Second, to those without whom this research would, quite literally, not have been possible: I thank the individuals who agreed to be participants in this research. They tolerated my observations and interviews with warmth and good humour. To John Storey, Brett Biddington, Matthew Colless, Will Saunders, Tony Travouillon, Jon Lawrence, Steve Gower, Francis Bennet, Jesse Cranney, Joe O'Leary, Samantha Le May, Steven Freeland, and others involved with PILOT and SERC who did not wish to be named in my research, but who nonetheless contributed their time and expertise, I offer the following: I did my best to write something that matters. I hope you like it, but if you don't, you may find comfort in the one fact that is incontrovertible — that nobody reads PhD theses anyway.

Third, to those who assisted with proofreading and helpful comments along the way: I thank my parents Alison and Bruce Handmer (who are partially responsible for how I got this way) and my bonus parents Jennifer Clark and Wade Smith (who should have known better) for their incredible kindness and generosity, and for hunting down typos. Thanks also to Benjamin Pope, whose expertise in astrophysics and astronomy, along with an astonishingly broad general knowledge, have facilitated countless wide-ranging and fascinating conversations, and who provided valuable input during the editing process. I am also grateful to Amy O'Donnell, one of the few people in the world who actually knows how to use a semicolon, and Georgina Dixson, whose work actually saves lives, for their proofreading skills. Additionally, I would like to thank Lucia Cafarella for her invaluable assistance transcribing hours of interview recordings, which was made possible through the support of Sydney University Disability Services.

Finally, I thank the many people — friends, family, mentors, colleagues, fairy godparents — who have come with me on this PhD journey in all sorts of ways. You know who you are. Thank you.

This thesis was mostly researched and written on the unceded lands of the Ngunawal and Gadigal peoples. I wish to acknowledge and condemn the historical and ongoing destruction of knowledge that is enabled by those who did not and will not recognise the value of what they choose not to try to understand.

For all the technologies we’ve loved and forgotten.

Contents

Figures

Acronyms

AAAAC	Australian Antarctic Astronomy Advisory Committee
AAD	Australian Antarctic Division
AAL	Astronomy Australia Limited
AAO	Australian Astronomical Observatory / Anglo-Australian Observatory
AASTINO	Automated Astronomical Site Testing International Observatory
AASTO	Automated Astronomical Site Testing Observatory
ABC	Australian Broadcasting Corporation
ACNC	Australian Charities and Not-for-profits Commission
ADAM	Area Defense [sic] Anti-Munitions system
ADFA	Australian Defence Force Academy
ADR	Active Debris Removal
AGO	Automated Geophysical Observatory
AITC	Advanced Instrumentation and Technology Centre
ALADIN	Accelerated Laser Demonstration Initiative
AMOS	Advanced Mechanical and Optical Systems SA
ANSOC	Astronomy NCRIS Strategic Options Committee
ANT	Actor Network-Theory
ANU	Australian National University
ANU RSAA	Australian National University Research School of Astronomy and Astrophysics
AO	Adaptive Optics
AOD	Adaptive Optics Demonstrator
AOI	Adaptive Optics Imager / Imaging
AOTP	Adaptive Optics Tracking and Pushing system
ARC	Australian Research Council
ARC LIEF	Australian Research Council Linkage Infrastructure, Equipment and Facilities scheme
ARENA	Antarctic Research, European Network for Astrophysics
ASIC	Australian Securities and Investments Commission
ASKAP	Australian Square Kilometre Array Pathfinder
ASRP	Australian Space Research Program
ATHENA	Advanced Test High Energy Asset
AUSLIG	Australian Surveying and Land Information Group
BCO	Beam Combining Optics
BTO	Beam Transfer Optics
CARA	Centre for Astrophysical Research in Australia
CCAA	Chinese Centre for Antarctica Astronomy
CEO	Chief Executive Officer

COO	Chief Operating Officer
CRC	Cooperative Research Centre
CRCA	Cooperative Research Centres Association
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DDP	Design and Development Phase / Program
DE	Directed Energy
DFAT	Department of Foreign Affairs and Trade
DM	Deformable Mirror
DMT	Douglas Mawson Telescope
DoD	US Department of Defense [sic]
E-ELT	European Extremely Large Telescope
EIF	Education Investment Fund
ELT	Extremely Large Telescope
EOS	Electro Optic Systems
EOS SS	EOS Space Systems
EPICA	European Project for Ice Coring in Antarctica
FCC	Federal Communications Commission
FTE	Full Time Equivalent
GFC	Global Financial Crisis
GM	General Manager
GMT	Giant Magellan Telescope
GMT-DDP	Giant Magellan Telescope Design and Development Phase
GSL	Guide Laser Star
HPL	High Power Laser
IP	Intellectual Property
IPEV	Polar Institute Paul-Emile Victor
IPG	IPG Photonics Corporation
IR	Infrared
ITAR	International Traffic in Arms Regulations
JACARA	Joint Australian Centre for Astrophysical Research in Antarctica
JWST	James Webb Space Telescope
KDUST	Kunlun Dark Universe Survey Telescope
LCH	Laser Clearing House
LEO	Low Earth Orbit
LGS	Laser Guide Star
LGSF	Laser Guide Star Facility
LIDAR	Light Detection and Ranging
LLT	Laser Launch Telescope
LMC	Lockheed Martin Space Systems Company

Chapter 1: Introduction

Figure 1 — Will Saunders and David Burgess on the sail of the Sydney Opera House in 2003.[1]

> *The history of technology is part and parcel of social history in general. The same is equally true of military history, far too long regarded as a simple matter of tactics and technical differentials. Military history too can only be understood against the wider social background. For as soon as one begins to discuss war and military organisation without due regard to the whole social process, one is in danger of coming to regard it as a constant, an inevitable feature of international behaviour. In other words, if one is unable to regard war as a function of particular forms of social and political organisation and particular stages of historical development, one will not be able to conceive of even the possibility of a world without war.*
>
> **John Ellis, The Social History of the Machine Gun**[2]

At 8:45am on 18 March 2003, Dr William Saunders, a British astronomer, and Dave Burgess, an activist he'd met through the Wilderness Society, ran up the largest sail of the Sydney Opera House carrying red paving paint and rollers. In an act of protest, they painted the words "NO WAR" in capital letters on its side. They were protesting the announcement by then Prime Minister John

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[1] Tsikas, M. (2003). Will Saunders and David Burgess climb the Sydney Opera House to paint the slogan "NO WAR". From Begg, Z. (2015). Moments Before War: the Sydney Snow Dome. MAAS Magazine, Powerhouse Museum.

[2] Ellis, J. and E. C. Ezell (1986). The Social History of the Machine Gun, Johns Hopkins University Press. pp. 9-10.

Howard that Australia would be joining the ‘Coalition of the Willing’ and contributing military support to the US action in Iraq the following day. Saunders and Burgess were both arrested, and were charged with the “offence of maliciously damaging property”.[3] While Burgess was an Australian citizen, Saunders was British. Having obtained his PhD in statistical cosmology in 1990 at Queen Mary and Westfield College, Saunders moved to Australia in July 2000 to work at the Anglo-Australian Observatory as an instrument scientist. Deeply principled and thoughtful, Saunders was midway through explaining to reporters how much he loved Australia and that he would help to clean the paint off the sails when he was arrested again, this time at the request of the immigration department.[4]

In his written statement, taken on 10 April 2003, Saunders spoke of his “mounting horror” at what he perceived as the likely “unprovoked invasion of Iraq”, and “the likelihood of British and Australian involvement in the invasion”.[5] He noted the actions he had taken including writing letters, participating in rallies, and even considering seriously becoming a ‘human shield’ by flying to Amman.[6] Saunders felt that Prime Minister John Howard had “deliberately misled the Australian people on his intentions to go to war, and had intended to ignore the democratic voice of the people from the outset”.[7] With “all legitimate means of preventing an illegal war” closed off, Saunders “resolved to knowingly break the law, to do the best I could to prevent this hugely greater crime”.[8] In court, Saunders and Burgess argued that the war was “unjustified and illegal”, and would “as a necessary consequence” lead to the deaths of people in Iraq, and that their words ‘NO WAR’ were therefore an act of self-defence.[9] Judge Blackmore ruled that the defence was not credible enough to warrant being heard by a jury,[10] and Saunders and Burgess were fined $151,000 to be paid in compensation for the damage to the Sydney Opera House and the cost of the paint’s removal, and sentenced to imprisonment “for a fixed term of nine months to be served by way of periodic detention”.[11] Saunders and Burgess appealed the decision unsuccessfully.[12]

In an effort to raise money to pay the fine, Saunders and Burgess held art shows, benefit concerts, and sold ‘glitter domes’ with models of the Opera House, bearing its ‘NO WAR’ addition.[13] One of these ‘snow globes’ (or ‘glitter domes’) sits in Old Parliament House, Canberra.[14] One was exhibited in 2015 in ‘Disobedient Objects’ by the Museum of Arts and Sciences.[15] And in the course of carrying out my research, I stumbled across another on the desk of Professor John Storey (see Figure 2).

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[3] (2005). R v BURGESS; R v SAUNDERS [2005] NSWCCA 52.

[4] (2003). "News in Brief: Stargazer Sees Red." Nature **422**(6930): 366-366.

[5] Saunders, W. (2003). "Statement on the Events of 18th March 2003." Sydney Opera House NO WAR Cleanup Fund https://web.archive.org/web/20070106050330/http://www.sydneyoperahousenowarcleanupfund.org/april_statements.html 2021.

[6] Ibid.

[7] Ibid.

[8] Ibid.

[9] (2005). R v BURGESS; R v SAUNDERS [2005] NSWCCA 52.

[10] Saunders, W. (2020). Research Interview. HREC 2020/145. A. Handmer.

[11] (2005). R v BURGESS; R v SAUNDERS [2005] NSWCCA 52.

[12] (2004). Opera House Graffiti 'an Act of Self Defence'. The Sydney Morning Herald, Fairfax Media.

[13] Saunders, W. (2003). "Quality 'NO WAR' glitter domes, fridge magnets, cards, stubbie holders, T-shirts - All proceeds to cleanup fund." Sydney Opera House NO WAR Cleanup Fund https://web.archive.org/web/20050404075443/http:/www.sydneyoperahousenowarcleanupfund.org:80/ 2021. See also Burgess, D. (2009). Activists Lost the War - but Won the Last Battle. The Sydney Morning Herald, Fairfax Media.

[14] Begg, Z. (2015). Moments Before War: the Sydney Snow Dome. MAAS Magazine, Powerhouse Museum.

[15] Ibid.

Storey is a now retired Antarctic astronomer who, in the years following Saunders' arrest, led the team that proposed 'PILOT', the 'Pathfinder for an International Large Optical Telescope', a telescope to be built at Dome C, one of the highest points on the Antarctic continent.[16] Storey, and his colleagues at the University of New South Wales, believed that a telescope placed on the high Antarctic plateau could outperform one twice the size at "the best mid-latitude observatories", and that an interferometer at the location could even be an alternative to a space telescope.[17] In fact, Storey and Saunders spent a year working closely together on the technical design of PILOT, deciding the instrumentation that would be required, and developing possible solutions to the complex challenges posed by the cold, dry environment of Antarctica. In an interview with me, Storey described Saunders as "one of the most amazing people I've ever met".[18] He respected Saunders' "freethinking" approach to issues of morality, as well as his capability as a scientist. The 'NO WAR' glitter dome Storey bought to help raise money for Saunders' fine is one of his most treasured possessions.

Figure 2 — Storey's NO WAR snow globe. Photographed by me with permission from Storey, December 2020.

Ultimately, PILOT failed to obtain funding and was never built under Australian auspices. As dreams of PILOT petered out, a number of the same individuals and organisations who had been involved in the project went on to work on another sweepingly ambitious project called the Space Environment Research Centre (SERC). SERC was a government-funded Cooperative Research Centre (CRC) which brought together academia and industry with the goal of building a high power laser and adaptive optics system capable of tracking, characterising, and ultimately manoeuvring space debris in orbit. Between 2014-2020, on an estimated budget of approximately $60 million, SERC operated out of

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[16] Storey, J. (2020). Research Interview 1 of 2. HREC 2020/145. A. Handmer.; Storey, J. (2020). Research Interview 2 of 2. HREC 2020/145. A. Handmer.

[17] "A telescope placed at Dome C would compete with one that is 2 to 3 times larger at the best mid-latitude observatories, and an interferometer based at this site could work on projects that would otherwise require a space mission". Lawrence, J. S., M. C. B. Ashley, A. Tokovinin and T. Travouillon (2004). "Exceptional Astronomical Seeing Conditions Above Dome C in Antarctica." Nature **431**: 278–281. p. 279.

[18] High praise from someone who, in 1984, published a scientific paper with the Proceedings of the Astronomy Society of Australia written in the form of a 38-stanza poem.

Mount Stromlo. In contrast to PILOT, SERC's failure was that it never managed to achieve its stated goal – demonstrating a remote manoeuvre of space debris – during its operational years.

The opening episode of Saunders and Burgess's 'NO WAR' protest illustrates my initial motivation for undertaking this research: to examine what the phrase 'dual-use', the term usually used to describe technologies that have civil and military applications, actually entails in practice. It is a broad consensus across scholarship in Science and Technology Studies that science is not, and has never been "pure". Scientific research as entirely disconnected from worldly, or more concretely: political, financial, or military interests is fiction.[19] Yet the acceptance of this constitutive hybridity from an academic perspective should not blind us to the fact that the institutional and legal frameworks for doing science also span a space for the moral and ethical frameworks within which researchers themselves operate in practice. This observation is perhaps particularly pertinent for the space research sector. In the case of SERC, for example, obtaining large-scale funding was synonymous with collaboration between participants from civil and military sectors. I am not seeking to draw normative conclusions in this study; rather, I examine how technical, institutional, and legal factors were structurally interlinked in practice, and what these structural links entailed for individuals' diverse conceptions of their role as moral and ethical actors.

This thesis presents a detailed, participant-observer based empirical examination of PILOT and SERC, two recent Australian space science projects. Through my research, and following numerous individuals who worked on both projects, I show that the Australian space science funding and policy environment changed significantly in the brief period between PILOT's unsuccessful proposal and SERC's formation, marking the period of time in which dual-use space capability development was recognised as a political strategic priority. I also illustrate the ways in which SERC's specific institutional structure, enabled by policy and funding conditions in Australia, allowed individuals working in, and adjacent to, the space sciences to maintain, unchallenged, the convenient fiction that science is itself amoral and, to some extent, apolitical.

Why PILOT and SERC? In a little-known chapter of PILOT's proposal for funding, a small camera, designed by Saunders himself, was added to PILOT's design, instrumentalising an additional science case that proposed to image and track space debris in polar orbits. The team behind PILOT felt that, even as early as 2006, appealing to a growing commercial and security interest in observing objects in orbit would increase the chances of the project receiving government funding. Space debris is a commercially pressing problem with immediate defence-related implications. Around the time PILOT was proposed, the concept of actively tracking debris and functional satellites in a non-classified setting was gaining traction as 'Space Situational Awareness' (SSA).[20] The addition of the camera arguably would have made PILOT a dual-use facility, had it been built. SERC, on the other hand, openly contemplated dual-use technology, framing the project as a moral and practical imperative to address the commercial and environmental threat posed by growing amounts of space debris.

Yet throughout the course of my inquiries into the imaging and tracking (PILOT) and prediction and manipulation (SERC) of space debris, what emerges is a clear paradox. On the one hand are the conversations that are being had by experts in various aspects of the space sector (astronomers, entrepreneurs, environmentalists, lawyers, archaeologists, policy writers) about everything from the

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[19] Shapin, S. (2010). Never Pure: Historical studies of science as if it was produced by people with bodies, situated in time, space, culture, and society, and struggling for credibility and authority. Baltimore, Md, Johns Hopkins University Press.

[20] Kennewell, J. A. and B. Vo (2013). An Overview of Space Situational Awareness. Proceedings of the 16th International Conference on Information Fusion.

importance of removing debris through to which debris should be removed and how it might best be done. In academic and industry circles, ideas have circulated about the use of nets, harpoons, space-tugs, and lasers. On the other hand, there is an implicit understanding by these same individuals that actually removing the debris is currently an impossible task, legally, technically, and politically. Nonetheless, the appeal to the problem of space debris was an important part of PILOT's unsuccessful bid for funding, and the stated *raison d'être* for SERC's successful one. Through the lens of the problem of space debris, I analyse the social and organisation structure of two recent large-scale Australian-based space research projects. And inevitably, given the paradox of space debris as a pressing problem without any immediate technical or legal solutions, my analysis examines failure: PILOT's failure to obtain funding that, or so I show, was partly a failure to overcome the logistical problems of international research collaboration; SERC's failure to reach its initially stated goal of demonstrating the possibility of Active Debris Removal (ADR) — a failure that, as I shall trace in detail, was nevertheless reframed as a success. At SERC, the alliance between space sciences (particularly instrumentation, adaptive optics, and optical astronomy) and dual-use technology was rendered explicit through inter-organisational agreements and corporate structures. SERC's success story illustrates how the moral as well as legal questions raised by dual-use technology were addressed and organised to the point of losing all meaning in a specific, institutionalised way in the Australian research context.

Both PILOT's and SERC's 'stories' as I tell them here had to be carefully constructed from a variety of sources. Some were easily accessed, such as scientific publications, conference proceedings, and annual reports. However, most of the information that is necessary to present a fulsome picture of these programs is invisible to web as well as traditional archival searches, and could only be tracked down once I knew what to look for and where to look.[21] These sources include the formal report which announced that PILOT had not received funding, which was purposefully taken offline in the aftermath of the decision, but which can still be found through internet archives. Another useful source on the details of SERC's financial activities, which were progressively omitted from SERC's Annual Reports, were the notes to SERC's financial reports filed with the Australian Charities and Not-for-profits Commission. These reports were publicly available during the course of my research and provided a valuable source of insight for my analysis SERC's financial structures and procedures, but following SERC's deregistration in mid-2021, they are no longer accessible.

Most of the substantive analysis used to compile the information presented in this thesis is based in extensive fieldwork, carried out between 2018 and 2021. I took a flexible approach to fieldwork methodology depending on the situation and context. During the scoping phase (2018 to 2019) I combined direct observation with informal interviews as a participant-observer at conferences and in visits to SERC's offices at Mount Stromlo. For example, in 2019 I was invited by Storey to attend a conference on Antarctic Astronomy in Italy, at which I both observed proceedings and presented my research to the individuals I was observing. During this period I sought to embed myself, gaining an understanding of the invisible politics at play within the densely networked communities of individuals I studied.[22] I visited my research participants at their homes, hiked with them, ate with

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[21] Such materials might be seen as an extension of Latour and Woolgar's 'inscriptions', but rather than traces of scientific fact, they are here serving as residual evidence of commercial organisation: Latour, B., S. Woolgar and J. Salk (1986 [1979]). Laboratory Life: The Construction of Scientific Facts. Princeton, New Jersey, Princeton University Press [Sage Publications].; discussed in the context of online research in Beaulieu, A. (2010). "From Co-location to Co-presence: Shifts in the use of ethnography for the study of knowledge." Social Studies of Science **40**(3): 453-470.

[22] For more on the practicalities of insider / participant observer research see Labaree, R. V. (2002). "The Risk of 'Going Observationalist': Negotiating the hidden dilemmas of being an insider participant observer."

them, and danced with them. I met their families, and heard their stories, and they introduced me to other people who knew more than they did.[23] During this time I also became embedded in the Australian space industry itself, and in 2020 I was nominated to the Advisory Council of the Space Industry Association of Australia.[24] My broad involvement in discourse surrounding Australia's space activities has enabled me to form a rich understanding of the context within which my case studies fit.[25]

Having narrowed my focus to PILOT and SERC, and identified the individuals whose perspectives would be most valuable, I applied for and received ethics approval through the Sydney University Human Research Ethics Committee process to conduct formal, transcribed interviews. I then approached those I wanted to interview, providing them with the required Participant Information Form and Participant Consent Form. As might be expected, some individuals preferred not to put their perspective on record.[26] For those that did consent, I conducted a series of interviews from early 2020 to mid-2021 through video-chat. In our interviews, I asked my research participants to tell me stories, and to describe for me not only what had happened, but how they felt about it emotionally, professionally, and personally. At times, interviews were loosely structured, as participants answered questions about topics we had informally discussed during the scoping phase. At other times, interviews went off on long tangents. Rather than try to prescribe the content, I preferred to let my research participants direct me towards what they felt was important.[27] Based on the video recordings, I produced transcriptions which I then sent back to research participants so that they could correct any missed details, and, importantly, ask for certain parts of the content to be anonymised or redacted. This part of the process involved an element of negotiation, because part of what made the interview process valuable was the unstudied insight it gave into the ways individuals thought and operated within their social contexts.[28] At the same time, I was conscious that my research participants had jobs and relationships that were important, and I ultimately erred on the side of caution, choosing to omit content that I saw as being potentially deleterious even when it was not requested.[29] During this phase I also corresponded with research participants to

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<u>Qualitative Research</u> **2**(1): 97-122.; Beaulieu, A. (2010). "From Co-location to Co-presence: Shifts in the use of ethnography for the study of knowledge." <u>Social Studies of Science</u> **40**(3): 453-470.

[23] Taylor, J. (2011). "The Intimate Insider: Negotiating the ethics of friendship when doing insider research." <u>Qualitative Research</u> **11**(1): 3-22.; A detailed account of the unique relationships that emerge between researcher and research participants is offered by Coffey, A. (1999). <u>The Ethnographic Self: Fieldwork and the Representation of Identity</u>. London, SAGE Publications.

[24] (2021). "SIAA Advisory Council." <u>About the SIAA</u> Retrieved 19/03/2021, from https://www.spaceindustry.com.au/about-siaa/.

[25] See Law, J. (2004). <u>After Method: Mess in Social Science Research</u>. London, Routledge. for an elaboration of this context-driven approach, building on the tradition of fieldwork-based Science studies since Latour, B. (1987). <u>Science in Action: How to follow scientists and engineers through society</u>, Harvard University Press.

[26] See Garforth, L. (2012). "In/Visibilities of Research: Seeing and Knowing in STS." <u>Science, Technology, & Human Values</u> **37**(2): 264-285.

[27] Such an approach draws on the theory of 'Agential Conversations' as presented in Müller, R. and M. Kenney (2014). "Agential Conversations: Interviewing Postdoctoral Life Scientists and the Politics of Mundane Research Practices." <u>Science as Culture</u> **23**(4): 537-559. See also Finlay, L. (2002). "Negotiating the Swamp: The opportunity and challenge of reflexivity in research practice." <u>Qualitative Research</u> **2**(2): 209-230.

[28] Garforth writes about the challenges of negotiating access in Garforth, L. (2012). "In/Visibilities of Research: Seeing and Knowing in STS." <u>Science, Technology, & Human Values</u> **37**(2): 264-285.

[29] Such a practice is grounded in feminist approaches to STS that emphasise the ethical responsibility of the researcher-participant. See Puig de la Bellacasa, M. (2011). "Matters of Care in Technoscience: Assembling neglected things." <u>Social Studies of Science</u> **41**(1): 85-106.

clarify details and request additional information. Some participants (notably Storey) agreed to provide me with documents and photographs. I am grateful for their assistance.

Many histories of Australia's involvement in space activities focus on efforts in rocketry research in the late 1950s and 1960s, and present Australia as an early participant, even a leader, in space science and launch technologies.[30] The announcement in 2017 that Australia would form a space agency prompted a surge in research on the political history of Australia's involvement in the space sector. Kerrie Dougherty's 'Australia in Space' is perhaps the most comprehensive history, providing a chronological overview of Australian space activities that begins with early rocketry (fireworks and signals in the 1800s, and the 'rocketeers' of the 1930s), progresses to rocket activity at Woomera and the development of Australian satellites, gives an overview of more recent space science activities (including a brief mention of SERC) and concludes with an overview of the history of Australian space policy.[31] Alice Gorman's 2019 meditation on space debris ('Dr Space Junk vs The Universe') is part history, part autobiography, offering an archaeological approach that complements Kerrie Dougherty's more documentary style.[32] Gorman offers a narrative history of Australia's scientific space activities alongside a social history of space in the public imagination.[33] In general, these histories emphasise the early history of Australian space activities, presenting Australia as having been an early space pioneer that somehow lost its way.[34]

Some more recent histories have complicated or even contradicted this narrative. From a policy angle, Brett Biddington presents a history of Australia's engagement with space at a government level, suggesting that the recent change in a long history of "steadfast" refusal by the Australian Government to engage on space issues is driven less by commercial interests than by national security concerns.[35] Cait Storr likewise uses archival sources to show that Australia's apparent historical leadership in international space law and diplomacy — which seems to run contrary to the experiences of a "long-neglected" domestic space industry — might be better understood in the context of Australia's efforts in other political issues, including nuclear disarmament.[36] In his history

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[30] Dougherty, K. (2006). "Upper Atmospheric Research at Woomera: The Australian-built sounding rockets." Acta Astronautica **59**: 54-67.

[31] Dougherty, K. A. (2017). Australia in Space: a History of a Nation's Involvement. Hindmarsh, SA, ATF Press. SERC is mentioned on p. 157.

[32] Gorman, A. (2019). Dr Space Junk vs The Universe: Archaeology and the Future. Sydney, NewSouth Publishing, University of New South Wales Press. Dougherty, K. (2014). "Crowded Space: The problem of orbital debris." Issues (South Melbourne) **106**(106): 18-22.; For my review of Gorman's book, see Handmer, A. (2020). "Review: Dr Alice Gorman (2019) Dr Space Junk vs the Universe: Archaeology and the Future, NewSouth Publishing, University of New South Wales Press, Sydney." Historical Records of Australian Science **31**(1): 70.

[33] See in particular Ch. 2 'Journey Into Space': Gorman, A. (2019). Dr Space Junk vs The Universe: Archaeology and the Future. Sydney, NewSouth Publishing, University of New South Wales Press.

[34] Dougherty, K. (2017). Lost in Space: Australia dwindled from space leader to also-ran in 50 years. The Conversation Australia.; de Zwart, M. (2019). "South Australia's Role in the Space Race: Then and Now." Adelaide Law Review **40**(1): 63-73.; Dougherty, K. A. (2017). Australia in Space: a History of a Nation's Involvement. Hindmarsh, SA, ATF Press.; Dougherty, K. and M. L. James (1993). Space Australia: the Story of Australia's Involvement in Space, Powerhouse Pub.; Blake, D. and T. Lange (2018). "A New Horizon: Australia in the global space race." Australian Quarterly **89**(3): 8-16,44,46.

[35] Biddington, B. (2021). "Is Australia Really Lost in Space?" Space Policy **57**: 101431.

[36] Storr, C. (2021). Why did Australia sign the Moon Treaty? The Interpreter, The Lowy Institute.; Desmond Ball's account of Australia's classified space activities supports the view that involvement in the space sector has been historically motivated by international affairs and Australia's alliance with the UK and the USA: Ball, D. (1988). Australia's Secret Space Programs. Canberra Papers on Strategy and Defence. Canberra, Australia. **43**. pp. 68-70,

of the politics surrounding early Australian involvement in space Tristan Moss explicitly contradicts the historical narrative of Australia as a space pioneer, emphasising instead the reluctance of the Australian Government to participate in space activities.[37] In drawing the boundaries of 'space activities', I agree with Moss's assessment that matters of Australia's space policy and administration should receive more scholarly attention than they do currently. However, Moss goes on to argue that astronomy should *not* be included in histories of space activities because astronomy projects cost significantly more than other space activities, "attract different types of government policies", and "have vastly different meanings in the public mind".[38] Both PILOT, an astronomy project, and SERC, a project which brought astronomers and the instrumentation of astronomy together with 'space industry' to form a single organisation, problematise such a segmented approach by their very existence. As this thesis will demonstrate, excluding astronomy wholesale from analyses of Australia's space sector (an approach which is not uncommon in the Australian space industry) misses what I show are very real and important overlaps of funding, policy, technology, and personnel that have real effects and implications for Australia's space activities.

Australia's space history and current space activity is unique, internationally, in a number of key ways. Australia's small size (economically, if not geographically) means that scientific projects compete for a limited amount of funding in a manner more concentrated than in the USA, where there is a stronger legacy of government spending on public scientific programs. Australia also has a different approach, socially, politically, and economically, to military funding. Thus, the distinction drawn by historians between Australia's space history and that of the USA may be understood as being partly a function of entirely different political, economic, and social contexts. As Moss draws the contrast, space history in Australia tends to be narrow in focus, and often motivated by the desire to influence policy,[39] whereas the more extensive tradition of American space history comprises "government-commissioned histories through the NASA History Office, academic studies and a vast body of popular works, much of it focusing on the Apollo era and human spaceflight".[40]

It is worthwhile, however, briefly mentioning some influential US-centric works in the field of Science and Technology Studies (STS) more specifically. Researchers such as Asif Siddiqi and Roger Launius have written extensively on the history of space activities in the Cold War context, documenting the space race and the contested narratives that shape understandings of space and of the impetus for government expenditure on the development of space technologies.[41] Lisa Ruth Rand likewise embeds her extensive history of space debris in the context of the Cold War, tracing the emergence of the conceptualisation of space as an 'environment'.[42] Much of this work is archive-based and historical in nature. Others, such as Janet Vertesi in 'Seeing Like a Rover', which presents an ethnographic account of the visualisation practices of scientists working on the Mars Exploration Rover mission,[43] have produced detailed contemporary analyses of space research. While such

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[37] Moss, T. (2020). "'There Are Many Other Things More Important to Us Than Space Research': The Australian Government and the Dawn of the Space Age, 1956–62." Australian Historical Studies **51**(4): 442-458.

[38] Ibid. pp. 443-444.

[39] Ibid. pp. 444-445.

[40] Ibid. p. 444.

[41] See, for example: Siddiqi, A. A. (2010). "Competing Technologies, National(ist) Narratives, and Universal Claims: Toward a Global History of Space Exploration." Technology and Culture **51**(2): 425-443.; Launius, R. D. (2019). Reaching for the Moon: A Short History of the Space Race. New Haven, Yale University Press.

[42] Rand, L. R. (2016). Orbital Decay: Space junk and the environmental history of Earth's planetary borderlands. 10191526 Ph.D., University of Pennsylvania.

[43] Vertesi, J. (2015). Seeing Like a Rover: How Robots, Teams, and Images Craft Knowledge of Mars, University of Chicago Press. See also Vertesi, J. (2012). "Seeing Like a Rover: Visualization, embodiment, and interaction on the Mars Exploration Rover Mission." Social Studies of Science **42**(3): 393-414.

research quite literally expands the research tradition of laboratory studies to settings including Mars,[44] it does not engage in any detail with the political or geopolitical context for space research.

An effort to address current challenges posed by space research, and to anticipate future such challenges, has characterised the intersection of space law and policy. In recent years, scholars in international space law have drawn attention to the problem of co-existing in a global commons, tackling such topics as space security and space sustainability, both of which have close ties to space debris and dual-use technologies. Space law and policy practitioners have looked ahead, identifying issues likely to arise in future, and pre-emptively discussing legal solutions. For example, Steven Freeland has highlighted the challenges that technological development poses for space law, and insists that developing legal frameworks that "properly address the demands and inevitability of technological innovation and an increasingly globalised and connected world" is imperative.[45] Space law and policy discussion is uniquely grounded in foresight, because forming consensus-based international law is a lengthy process. Richard Wilman and Christopher Newman's book 'Frontiers of Space Risk: natural cosmic hazards & societal challenges' presents a range of future issues and discusses possible legal implications.[46] In 'Global Commons, Cosmic Commons' Cassandra Steer writes about the practical implications of the interplay between civil and military uses of space, arguing that state practice has prompted the need to clarify international space law frameworks.[47] Some have advocated for legal solutions to the growing problems, such as through non-binding instruments such as the United Nations Guidelines for the Long-Term Sustainability of Space Activities,[48] while others have gone further, advocating for the formation of new treaty law.[49] At the same time, some space law researchers and practitioners, such as Setsuko Aoki, have emphasised the importance of soft law and diplomacy.[50]

In the specific field of space sustainability and debris management, Moriba Jah examines the interplay between technological solutions and legal frameworks, arguing for a greater focus on transdisciplinary engagement that combines quantitative study of space with protocols and

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[44] For a history of the development of laboratory studies in STS, see Guggenheim, M. (2012). "Laboratizing and De-laboratizing the World: Changing sociological concepts for places of knowledge production." History of the Human Sciences **25**(1): 99-118.

[45] Freeland, S. (2017). "The Changing Nature of Space: Future challenges for space law." Law Society Journal(39): 82-83. For a discussion of future legal complications arising from planned small satellite constellations, including the increasing risks posed by debris, see Freeland, S. (2020). Legal Issues Related to the Future Advent of Small Satellite Constellations, Springer International Publishing**:** 1315-1336.

[46] Wilman, R. J. and C. J. Newman (2018). Frontiers of Space Risk: natural cosmic hazards & societal challenges. Boca Raton, FL, CRC Press, an imprint of Taylor and Francis.

[47] Steer, C. (2017). "Global Commons, Cosmic Commons: Implications of Military and Security Uses of Outer Space." Georgetown Journal of International Affairs **18**(1): 9-16.

[48] Johnson, C. D., B. Weeden, V. Samson, L. Delgado López and M. Simpson (2014). "The Importance of the United Nations Guidelines for the Long-Term Sustainability of Space Activities and Other International Initiatives to Promote Space Sustainability." OASIS(20). For a succinct overview of the multifaceted problem of space sustainability see Johnson, C. D. (2018). Space Sustainability. Frontiers of Space Risk. R. J. Wilman and C. J. Newman, CRC Press**:** 165-187.

[49] For example, Daniel Porras has examined the impact of space warfare on the growing debris challenge and investigates the possibility of forming new space law on issues of space security, specifically addressing the issue of the weaponization of space in Porras, D. (2019). "Anti-satellite Warfare and the Case for an Alternative Draft Treaty for Space Security." Bulletin of the Atomic Scientists **75**(4): 142-147.

[50] Aoki, S. (2012). The Function of 'Soft Law' in the Development of International Space Law. Wien, Böhlau Verlag. **102:** 57-86. See also Freeland, S. (2012). The Role of 'Soft Law' in Public International Law and its Relevance to the International Legal Regulation of Outer Space. Soft Law in Outer Space: the Function of Non-binding Norms in International Space Law. I. Marboe. Austria, Bohlau Publishing**:** 9-30.

procedures.[51] In similar intersections of theory and practice, the field of space law has also grappled with the practical challenges for dual-use technologies arising from export controls,[52] pointing to the important role technological development plays in sustainable uses of space.[53] Current scholarship in this field suggests that is necessary to understand, in detail, the connection between technology and the surrounding social and political factors, in order to solve imminent legal problems. However, to date there has been a lack of empirical, case-study based research that shows how scientific and technological development is occurring 'on-the-ground', and interacts (or not) with international legal frameworks. Thus, the interpretive social studies of science lens that I employ in this thesis adds an important element currently missing from discourse on international law, space security, and space sustainability. The outcomes that emerge from my study have implications not only for an Australian context, but also for other jurisdictions.

On the broad topic of the interplays between the military and science, David DeVorkin has explored at length the important role that military funding played in the development of space sciences in the USA.[54] Peter Galison's foundational work 'Image and Logic' explores the historic shift in microphysics from small laboratories to big scientific enterprises, and the impact this change has had on people and institutions. In particular, Galison points to the emergence of 'trading zones', wherein individuals from different disciplines and from different organisations (including the military) exchange information and coordinate activity.[55] Audra Wolfe's 'Freedom's Laboratory: The Cold War Struggle for the Soul of Science' examines, through a historical lens, how individual scientists became instruments of propaganda, espionage, and psychological warfare during the Cold War, often unknowingly.[56] In 'How Technology Moves', John Krige assembles a collection of essays on the practical regulatory responses that have arisen in the present day as states try to control the production and transmission of scientific knowledge with national security implications.[57] Krige's own focus is on export controls, and the effects of regulation on transnational scientific cooperation.[58] In 'What is Science For?' Jon Agar outlines the resulting bind and opportunity that occurs for scientists when they encounter what Agar calls a 'working world'.[59] On the one hand, the problems that are encountered by military systems which require scientific input provide both the resources to scientists to work towards solving them and a justification for science itself. On the

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[51] Jah, M. (2020). Space Object Behavior Quantification and Assessment for Space Security, Springer International Publishing**:** 961-984.

[52] Samson, V. (2015). "Workshop Review: Export Controls of Space Systems." Astropolitics **13**(2-3): 118-122.

[53] Jah, M. (2020). Space Object Behavior Quantification and Assessment for Space Security, Springer International Publishing**:** 961-984.

[54] DeVorkin, D. H. (1992). Science with a Vengeance: how the military created the US space sciences after World War II. New York, Springer-Verlag.

[55] Galison, P. (1997). Image and Logic: a Material Culture of Microphysics. Chicago, University of Chicago Press. I draw on Galison's use of organisational charts particularly in Ch. 4, 'Laboratory War' (e.g. p. 245) in my treatment of SERC's organisational structure.

[56] Wolfe, A. J. (2020). Freedom's Laboratory: The Cold War Struggle for the Soul of Science, Johns Hopkins University Press.

[57] Krige, J. (2019). How Knowledge Moves: Writing the Transnational History of Science and Technology. Chicago, University of Chicago Press.

[58] Krige, J. (2019). Export Controls as Instruments to Regulate Knowledge Acquisition in a Globalizing Economy. How Knowledge Moves: Writing the Transnational History of Science and Technology. Chicago, University of Chicago Press**:** 62-92. See also Krige, J. (2019). "Regulating International Knowledge Exchange: The National Security State and the American Research University from the 1950s to Today." Technology and Culture **60**(1): 252-277.

[59] Agar, J. (2020). "What is Science For? The Lighthill report on artificial intelligence reinterpreted." The British Journal for the History of Science **53**(3): 289-310.

other hand, Agar writes that “the social institutions and norms of science have been shaped to provide scientists with a measure of autonomy and protection from working worlds”.[60] So arises a tension, with the scientist themselves at the centre. Through my case studies on PILOT and SERC I analyse at a practical level how organisational structures and funding and governance settings within Australia’s funding and policy context preserve the perceived ‘protection from working worlds’ for scientists while also providing the resources necessary to ‘do science’.

On the topic of military uses of space, Joan Johnson-Freese’s ‘Space Warfare in the 21st Century: Arming the Heavens’, outlines the ways in which US policy has adapted to developments in dual-use space technologies.[61] Everett Dolman’s ‘Astropolitik: Classical Geopolitics in the Space Age’ and ‘Can Science End War?’ deal explicitly with the social and political elements of military uses of space, contextualising them within the history of warfare more broadly.[62] On military technology in general, John Ellis’s now-classic ‘The Social History of the Machine Gun’ argues that military tactics and the history of machine gun warfare, and the adoption of technologies themselves, have historically been rooted in social structures and power relations.[63] In a popular treatment of military-industrial complex in the context of astronomy, Neil deGrasse Tyson and Avis Lang’s ‘Accessory to War: The Unspoken Alliance Between Astrophysics and the Military’ openly grapples with the co-dependence of astrophysics and military activities, noting that there is an overlap that benefits both industries.[64] In an Australian context, Brett Biddington has called for more explicit attention to be paid to “the implications of the dual use nature of many space technologies and of the orbital space environment itself”, suggesting that “a deliberate discussion about dual use technologies may serve to synthesise the national security and economic narratives into a unified whole”.[65]

On the ethics of military-applicable science, John Forge has argued that it is always wrong to design weapons,[66] and that scientists working on dual-use technologies also have moral responsibility for the outcome of their research.[67] Military ethicist Nikki Coleman has noted that many aspects of space activities, including space debris, give rise to ethical issues that go beyond questions of law.[68] Evie Kendal has gone further, raising the need for a global space ethics review system.[69] My research here is descriptive in nature, and steers clear of seeking to draw normative questions. It is my hope, though, that the case studies presented here provide an empirical basis on which further normative work can be done.

Let me give you a brief overview of the analysis that follows. In Chapter 2 I introduce PILOT, the Antarctic telescope, and argue why (and how) we should study failure, positioning PILOT within a broader tradition of failure studies. I then briefly trace the history of Australian involvement in

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[60] Ibid. p. 289.

[61] Johnson-Freese, J. (2016). Space Warfare in the 21st Century: Arming the Heavens, Taylor & Francis.

[62] Dolman, E. C. (2005). Astropolitik: Classical Geopolitics in the Space Age, Taylor & Francis, Dolman, E. C. (2015). Can Science End War?, Wiley.

[63] Ellis, J. and E. C. Ezell (1986). The Social History of the Machine Gun, Johns Hopkins University Press.

[64] Tyson, N. G. and A. Lang (2018). Accessory to War: The Unspoken Alliance Between Astrophysics and the Military, W. W. Norton.

[65] Biddington, B. (2019). Space Security in the 21st Century: Roles, responsibilities and opportunities for Australia. p. 6.

[66] Forge, J. (2019). The Morality of Weapons Research: Why it is Wrong to Design Weapons. Cham, Springer International Publishing.

[67] Forge, J. (2010). "A Note on the Definition of “Dual Use”." Science and Engineering Ethics **16**(1): 111-118.

[68] Coleman, N. (2020). "Ethical Challenges in Space: Norms and conventions for peaceful spacefaring." Journal and proceedings of the Royal Society of New South Wales **153**(477/478): 87-89.

[69] Kendal, E. (2018). ‘No Conscience of Its Own’: The Need for Global Space Ethics Review, Springer International Publishing**:** 261-274.

Antarctic astronomy, and the beginnings of a collaboration between Australia, France and Italy at Dome C, Antarctica. I provide a detailed examination of how PILOT's technical design and funding proposal were shaped by contemporary changes to Australia's funding and policy architecture, as well as by the harsh climate of the Antarctic plateau. I end Chapter 2 with an analysis of the collective imaginings of PILOT and the divergent narratives that emerged throughout my research about the extent to which PILOT would be a dual-use facility. In Chapter 3 I unpack the many factors that played into decisions not to fund PILOT, looking in particular at PILOT's position relative to Australian astronomy at the time, and in relation to international scientific collaboration. I then outline PILOT's place in reference to Australia's national strategic interests, and the changing landscape of Australia's burgeoning space industry.

In Chapter 4 I introduce SERC, the Space Environment Research Centre, and trace how the Cooperative Research Centre (CRC) funding structure became the mechanism by which Electro Optic Systems (EOS) and Australian National University's Research School of Astronomy and Astrophysics (ANU RSAA) formalised and funded joint research into adaptive optics and high power lasers. I then discuss how numerous institutions with varied interests and goals came together under one entity, systematically describing how SERC's research, organisational, financial, and social structures were created to support the delivery of the CRC's goals. In Chapter 5, I lay out SERC's experimental setup, tracing the organisational and technological challenges that resulted in delays and design changes, and how these were experienced by individuals at all levels of SERC's hierarchy. I then explain the parallel political and legal challenges that apply to the operation of Active Debris Removal (ADR) technology, specifically (in this case) concerning high power lasers. Finally, I describe how SERC was disassembled and how assets and IP were divided between partners. I outline how, despite a failure to carry out their stated goal for legal and technical reasons, SERC has been presented, unchallenged, as a success. In Chapter 6, I conclude with a discussion of how the structures underpinning PILOT and SERC, and the insistence throughout both projects that they were purely civil science, allowed those involved to sideline questions of moral and legal responsibility.

My research makes apparent through in-depth empirical study how dual-use technology has been developed through (substantially) publicly funded institutions and by civil scientists. On the basis of publicly available information, I point out that such technology is likely to be repurposed for its unspoken 'other' use in future. During the course of my research on this topic, I spoke to individuals with a vast range of attitudes to the development of military technology and weaponry. In light of current discussions in Australia on the need to develop sovereign space capability, some of which I have participated in (both through my role on the Advisory Council of the Space Industry Association of Australia and in a private capacity), there will be some readers of this research who will see SERC's development of high power laser technology and enhanced adaptive optics for Space Situational Awareness in particular as an overwhelmingly positive outcome. There will be others outside the sector for whom the revelation that a public and private-funded organisation comprised of civil-scientists employed by universities, in partnership with commercial entities, developed such technology will come as a surprise. In light of the complex and nuanced range of valid perspectives, my thesis explicitly avoids drawing normative conclusions as to how things 'ought' to be. Nonetheless, I argue that as a matter of public accountability, it is important to bring into view how decisions about public funding of dual-use research are made, what technologies result from that investment, and where those technologies end up. This is what I hope to have done in this thesis.

While my research is grounded in the experiences of individuals as they were related to me, it is not about individuals *per se*, but rather about the structures within which they operate. I write with respect for the scientists who have spent their careers balancing a genuine conviction that they are engaged in the pure and apolitical business of studying Nature with the pragmatic necessity of, to borrow Latour's phrase, "recruit[ing] countless allies while waiting for Nature to declare herself" within real life funding and structural research conditions.[70] What I do, by conducting a detailed empirical study of this kind, is to say the quiet part loud. I identify that the current arrangement of policy and funding structures in the Australian space sciences sector facilitates engagement in dual-use technology development in such a way that two outcomes emerge: first, that moral responsibility for the outcome of such research is institutionally and individually avoided by distributing it 'up the chain' to national governmental entities, and second, that international legal responsibility is likewise avoided at a national level by distributing it 'down the chain' to institutions and the private sector. In both cases, Australian policy and practice has delayed accountability. My hope is that by establishing an evaluative picture of how things are, policy-makers and ethicists will be able to have more informed discussions, and ultimately reach strategic conclusions about how things ought to be.

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[70] Latour, B. (1987). Science in Action: How to follow scientists and engineers through society, Harvard University Press. p. 97. There is a long history of literature on the division between morality and technical expertise as a prerequisite for technical advice on policy matters since the end of the Second World War (Shapin, S. (2004). The Way We Trust Now: The Authority of Science and the Character of the Scientist. Trust Me, I'm a Scientist. P. Hooodbhoy, D. Glaser and S. Shapin. London, The British Council: 42-63.) In keeping with this line of work, I too problematise the structures of allocating moral responsibility; my focus, however, is on researchers as moral agents regardless of their function as policy advisers.

Chapter 2: PILOT — a proposal for an Antarctic telescope

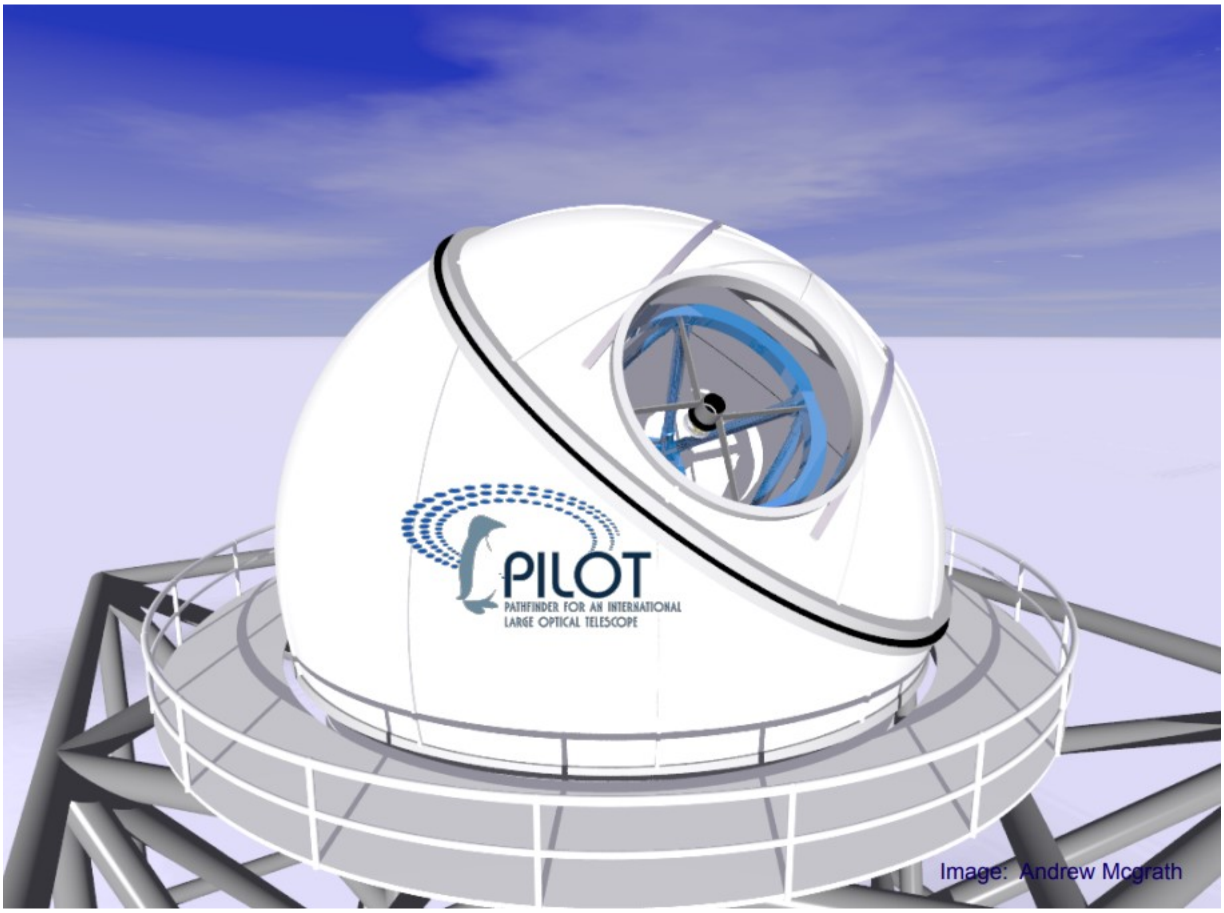

Figure 3 — A computer-generated mock-up of what PILOT might have looked like.[71]

2.1 Why study PILOT?

2.1.1 The end of PILOT

In early September 2008 a small group of five noted astronomers met to discuss the future of astronomy projects in Australia. As members of the Astronomy NCRIS (National Collaborative Research Infrastructure Strategy) Strategic Options Committee (ANSOC), their task was to decide how uncommitted government funding for astronomy research in Australia should be spent — and, by extension, which projects should not be funded.

Two members (Professor Michael Barber and Mr David Warren) were representatives from the Board of Astronomy Australia Limited, an organisation formed in 2007 to represent the views and interests of a consortium of Australian universities and other research organisations, and to manage the administrative burden of distributing government funds. The other three members were internationally acclaimed leaders in their fields — Professor Garth Illingworth from the University of

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[71] Burton, M. (2011). A Retrospective on the Science Drivers for PILOT: What kind of infrared astronomy to do from Antarctica? 'Beijing KDUST Workshop'. Beijing, China. slide 19. Image created by Andrew Mcgrath, a member of the PILOT Phase A study team.

California Observatories and Lick Observatory, Dr Robert Williams from the Space Telescope Science Institute, and astrophysicist Professor Malcolm Longair from the University of Cambridge.

Up for consideration for the favour of the ‘Strategic Options Fund’ of just over $5 million were three project proposals, with a combined estimated budget of $12 million. Arithmetic decreed: two projects would be funded, and one would miss out. With the release of the ANSOC Report on 19 September 2008, the fate of the Pathfinder for an International Large Optical Telescope (PILOT) was sealed. This bold proposal to build a telescope high on the Antarctic plateau failed.

Big scientific projects are pitched and rejected often. So why examine PILOT further? The last several decades of academic analysis of the intersections between science, technology and society have reinforced the value of studying failed and failing projects. Mumford Jones observed, back in 1959, that if the history of technology is a way of better understanding humanity, then “the ‘failures’ may be more illuminating than the ‘successes’”.[72] Failures may arise from a range of circumstances, Mumford Jones tells us, and deserve a “just and generous history”.[73] This chapter and the next provide a detailed history of a recent episode in Australian space science that ended in a kind of failure: PILOT. In this chapter I trace the historical context within which PILOT was imagined into being, and then outline the history of the design studies and preparations that went into the 2008 proposal. In the next chapter, I examine how it was that PILOT got as far as it did, but never quite came to fruition.

Giving an account of failed scientific projects, or, in this case, bold technologies that were never built, can be difficult. Accurate traces of what almost happened are not straightforward to follow, even when, like PILOT, the project’s very recent ghost haunts the pages of departmental reports, scientific papers, and living memory. Based on extensive interviews with researchers involved in PILOT, the project’s social history that I offer here reveals some of the first hints of what would become, a few years later, a close and entangled relationship between space debris, dual-use technology, and astronomy in Australia. It also provides important insights into the changing structure of Australian space science funding, and the political, economic, scientific, and social shifts that have brought the sector to where it is today.

2.1.2 Why and how to study failure

Let me begin with a brief reminder of the recent appeal of the study of failure in the field of Science and Technology Studies (STS). As Reinhold Bauer notes, the study of failure has continued to be of interest to successive generations of scholars, but the practice began in earnest in the 1980s, facilitated by the shift by sociologists of technology towards considering technology as being socially constructed.[74] Once technology is reinstated within its social context, it is possible to study failure (or success) in a way that acknowledges that processes, people, and politics are equally as influential on an outcome as non-human, technological and scientific elements. As Bauer puts it neatly, “the ‘best’ technology does not always succeed”.[75]

Social constructivist approaches gained popularity among STS scholars from the 1970s as both a theoretical and practical response to the way in which realist approaches to scientific phenomena

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[72] Mumford Jones, H. (1959). "Ideas, History, Technology." Technology and Culture **1**(1): 20-27. p. 25.

[73] Ibid. p. 25.

[74] Bauer, R. (2014). "Failed Innovations — Five Decades of Failure?" Icon, Journal of the International Committee for the History of Technology **20**(1): 33-40. p. 34-35.

[75] Ibid. p. 35-36.

neglected to account for "the social and cultural context of knowledge itself".[76] The production of facts, according to social constructivists, is an active and socially mediated process.[77] The laboratory, for example, produces a version of 'nature' in pursuit of whatever approximation of 'truth' can be demonstrated to work.[78] Similarly, the representations produced through the use of instruments such as telescopes or microscopes are not direct mirrors of nature, but achieve their significance through human acts.[79] The assumption that underpins the diversity of social constructivist approaches to science and technology is that the scientific study of nature is not a direct translation of an objective reality into objectively true facts. Instead, the process of producing scientific knowledge is inevitably social in nature, and knowledge is therefore socially mediated. Associated with the programmatic 'symmetry principle,' the investigation of the 'losers' rather than only winners of scientific controversies became a standard analytic tool in Science Studies.

From this theoretical starting point, STS scholars have spent decades trying new and interesting ways of tracing, explaining, communicating, and sifting through the layered and messy social interactions that together make up 'science' and produce what we call 'knowledge' and its material technological embodiments.[80] One such attempt is in Bruno Latour's 1996 'scientifiction' murder mystery, 'Aramis, or, the love of technology'.[81] In this work, Latour puts into action the theoretical approach he (alongside other scholars) has famously advocated since the 1980s: Actor-Network-Theory (ANT). ANT characterises the social situation in which technology 'happens' by identifying and investigating the network of relationships that exist between human and non-human components of a scientific or technological project. In Aramis, and crucially for my work here, Latour's chosen topic is a high-profile failure. High hopes were pinned on ARAMIS, a driverless train that was intended to solve Paris's transportation problems — but, as Latour's story documents in detail and through a combination of interviews and documents from bureaucrats, scientists, and indeed the train itself as a non-human actor, the train was never built. Why? The problem was not that the idea of a driverless train was too ambitious: the city of Lille, in northern France, runs precisely such a system. Rather, Latour's detailed analysis of the slow "death" of the ARAMIS project in Paris highlights the necessity of the integration of social dynamics and purely technical or scientific innovation for a project to 'work.'

This is the theoretical insight I build upon in the two recent-history case studies that follow, PILOT and, in Chapters 4 and 5, SERC. Failure, perhaps more so than success, brings out the social component of research such as that of the large-scale space science projects that I will investigate. However, there are also some important differences with Latour's approach. Firstly, ARAMIS, as presented by Latour, might well have been a successful project. PILOT, on the other hand, was never an infrastructural priority and there are any number of well-documented reasons why it was not built. Secondly, the definition of failure is clear enough in Latour's Aramis: ultimately, there was no new, driverless train system in Paris. But an important insight from my investigation both of PILOT

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[76] Mendelsohn, E. (1977). The Social Construction of Scientific Knowledge. The Social Construction of Scientific Knowledge. E. Mendelsohn, P. Weingart and R. Whitley. Dordrecht, Springer. **1**. p. 3.

[77] Latour, B. (1988). The Pasteurization of France. Cambridge, Mass, Harvard University Press.

[78] See Knorr-Cetina, K. (1981). The Manufacture of Knowledge: an essay on the constructivist and contextual nature of science. Oxford, Pergamon Press.

[79] For more analysis on the effect optical instruments have on the process of constructing knowledge, see Wilson, C. (1996). "Instruments and Ideologies: The Social Construction of Knowledge and Its Critics." American Philosophical Quarterly **33**(2): 167-181.

[80] For a brief introduction to social constructivism, see Sismondo, S. (2010). The Social Construction of Scientific and Technical Realities. An Introduction to Science and Technology Studies. Chichester, England, Wiley-Blackwell.

[81] Latour, B. (1996). Aramis, or, the Love of Technology. Cambridge, Mass, Harvard University Press.

and SERC is that the very definition of failure in contemporary large-scale space science projects in Australia is the product of social processes in a shifting landscape of forging research and funding collaborations. To anticipate what I'll trace in detail below, PILOT failed simply in the sense that it wasn't built. I call PILOT a 'failure' because this is the terminology through which my academic field makes sense of such project proposals that, in the kinder language of astronomy and astrophysics, do not 'get up'. I do not claim that PILOT was a failure in any sense other than that the proposal in 2008 failed to win funding, and PILOT was never built. SERC, on the other hand, failed to operate its proposed prestige experiment, laser-induced repositioning of space debris, yet has not been challenged in presenting itself as a success.

This problematisation of the notion of failure itself also has its precedents in the Science Studies literature, such as in Peter Galison's probing of the notion of closure in scientific arguments in his 'How Experiments End.' As Galison argues, the endings of research projects are socially constructed too: the acceptance of the "validity of an experimental conclusion" is a social process of negotiation over accepted standards of evidence, standards that shift drastically over the course of historical time.[82] In my analysis of PILOT, I investigate analogous processes of negotiating closure in the present — not of a scientific experiment as in Galison's study, but rather of the proposal to establish the infrastructure for such experiments, i.e. the PILOT proposal. This investigative angle foregrounds the very different perspective involved in the negotiations: what was it that led some of the involved actors to believe firmly that the project would succeed when it seemed clear to others that it would necessarily fail?

The PILOT example illustrates how failure is shaped in curious and subtle ways by the structure of social organisation. My investigation of what comes to constitute failure draws attention to the peculiar mix of social, economic, political, and technological factors in the Australian space sciences context in the years between 1996 and 2008 that formed the unique structural landscape within whose bounds the idea of PILOT rose and fell. I seek to highlight the contingency of relatively expensive, high-profile research projects in this sector upon these interrelated, and, I contend, often not widely discussed factors. Change any of them — make a policy change that alters the criteria by which funding is distributed and to whom, lose the support of just one individual at a key strategic position within the institutions involved at a critical moment, create a new kind of research organisation which mixes individuals and expertise in new ways — and what you might have done is restructure failure itself.[83]

Before I launch into the concrete story of PILOT, let me address one more aspect in which Latour's work serves as a point of reference for mine: Latour's peculiar literary style in Aramis. Latour writes to engage the reader emotionally, playing off their stylistic associations, whether with conventions of STS literature or the murder mystery genre. As a piece of literary technology, Latour's ARAMIS is compelling. Latour slowly makes his reader fall in love with this ingenious, complicated, and enchanting train. His imagined conversations between components of its engine not only remind us that non-human actants are — on Latour's view, as performed in the text — part of the network of relationships that make up the social. They also evoke an emotional affection in us for the technology that makes it all the more heartbreaking when Latour tells us that ARAMIS died because

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[82] Galison, P. (1987). How Experiments End. Chicago, University of Chicago Press. p. 2.

[83] McCray, W. P. (2001). "What Makes a Failure? Designing a New National Telescope, 1975-1984." Technology and Culture **42**(2): 265-291.

no-one loved it enough. “Stop!” we want to shout. “We will love it! Give it back to us!” But the ‘train-in-the-freezer’ cannot be revived, because Latour’s drama relies on this device.[84]

On my reading, Aramis is as much a romance novel as it is anything else. Latour is not merely invoking emotion for the fun of it: he really is talking about the love of technology. My research bore out that some of PILOT’s conceptual architects have enduring, genuine affection for their processes, ideas, and technologies. Some of the individuals I spoke to in the course of my research articulated the emotional component of their relationship with PILOT and with their broader field of study more clearly than others. Storey, in particular, was quite explicit about his love for PILOT, in a way I could not easily write off as sentimentality or metaphor. In the course of our discussions I came to understand that his enthusiastic participation in my research was at least partially motivated by his need for closure. Of course, like Latour, when I write about ‘love’ I’m not trying to give an account of any individual’s inner life, or perform psychology on them based on their responses to my questions. To do so would be as impossible as it would be unethical. Instead, I’m drawing out a consistent thread that emerged in the stories that they chose to tell me, and the framing they chose to use to explain the project and their involvement in it to me.[85]

Aramis also works as a piece of literature because Latour is very up front about his work of ‘scientifiction’ being a kind of performance. Rather than asking his reader to suspend disbelief, Latour is almost Brechtian in constantly reminding us that what we are reading is not a factual report, but a conscious *representation* of reality. Like his version of ARAMIS, Latour presents us with characters who are deliberately arranged to share the right information at the right time, and to lead us down narrative paths. He creates a fictional ‘Professor Norbert’ who is a sort of alter-ego, but whose observations are only ever reported to us by the Young Engineer. As Clarke puts it, “Latour arranges to have it several ways — to be at once the literary author of a fictional narrative and the scholarly author of a fictional nonfictional discourse”.[86] He tells us from the start that this is not real life, it is a fictionalised account of real life, presented *as if* real. Latour self-consciously performs the process and act of construction in a manner both charming and disturbing: if Aramis is not about striving towards some objective ‘truth’, what is it about?

Like Aramis, my study of PILOT is based on a range of evidence which includes documents, reports, images, and interviews with real individuals. Like Latour, I am implicated in making these individuals perform for the reader. Unlike Latour, I do not claim to have produced a work of hybrid ‘scientifiction’: I have done my best to present humans and non-humans alike ‘factually’, in the way they appeared to me. But interviews, however carefully prepared methodologically, ethically approved, and eventually conducted, still remain a kind of invited performance, and the reader should not be fooled into the sense that they are reading anything more than a representation of reality, assembled with care from the variety of performances that each of these individuals gave for themselves, for each other, and for me.

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[84] For a quick explanation of ‘fridging’ or ‘Women in Refrigerators’, see Seale, J. (2018). From Bond to ITV’s Strangers: Why is everyone ‘fridging’? The Guardian. For more a more academic discussion, see Kent, M. (2021). ‘You Have a Knack for Saving My Life!’: Wives, Girlfriends and Women in Refrigerators in Marvel Films. Women in Marvel Films, Edinburgh University Press: 29-46.

[85] Jon Agar writes about the value in assessing differences between ‘relatively on- and off-the-record stances’ as a way in which we can gain insight into the way that scientists actually think about problems. See Agar, J. (2020). "What is Science For? The Lighthill report on artificial intelligence reinterpreted." The British Journal for the History of Science **53**(3): 289-310.

[86] Clarke, B. (2014). Observing ARAMIS, or the Love of Technology: Objects and Projects in Gilbert Simondon and Bruno Latour. Neocybernetics and Narrative, University of Minnesota Press: 111-138. p. 113.

All quotations below are direct reproductions of what was said in the interviews I conducted, details of which can be found in the reference list. Readers should be aware that the selection of those quotations from lengthy transcripts, their arrangement, their juxtaposition with other sources or with quotations from others, and the analysis I perform on, with, and by them, are all choices I have made. I have done my utmost not to misrepresent any individual, and at times have erred on the side of caution when selecting and framing quotes. Based on these interviews, and what primary documentation it was possible to track down, I have, like a director, produced a (mostly) cogent story, but importantly, I do not claim that it is in any way 'the objectively true history' of PILOT. Rather, this is a history that acknowledges openly that research participants and readers alike will bring their own lens to events.

I make no apology, though, if a reader falls in love with PILOT. Many of those I spoke to still hold a candle for what is an undeniably compelling piece of technology, situated (if only in our imaginations) in one of the most remarkable locations on Earth. Be warned, however, that, as we learned from Aramis, no amount of sociological study can resurrect PILOT.

2.2 Research context

2.2.1 Our story begins

I first heard PILOT's name mentioned in June 2019, on a late afternoon in the small mountain town of Courmayeur in Italy's Aosta Valley, in the foothills of Mont Blanc. I was sitting in the late afternoon sun with a small group of astronomers and astrophysicists who had gathered after the day's formal conference proceedings for a drink. I was invited as a participant-observer, during the scoping part of my research, to a meeting of the SCAR AAA, the Astronomy & Astrophysics from Antarctica research program of the Scientific Committee on Antarctic Research. The purpose of this meeting, the fifth such event since its first took place in 2011, was to bring together scientific representatives from the nations conducting astronomy in Antarctica to coordinate and share information on future plans.[87] As a researcher who was neither an astronomer nor ostensibly connected to Antarctica, I was an oddity.

Earlier that day, due to a last-minute gap in the program, I had been asked to present on some of my previous research on scientific cooperation in Antarctica, and to explain my current research focus. It was beginning to dawn on these scientists, who spent their professional lives observing far-off stars and galaxies, that as an STS scholar, I might be there observing *them*. They were understandably curious about what I hoped to gain from being there. I told them that I was hunting down failures: big, international, cooperative scientific projects that didn't happen. I wasn't there to judge what happened, but instead to try to explain and understand it. Among the various examples that were thrown around the table in response, PILOT stuck in my mind, principally because the person who mentioned it, Professor John Storey, returned to the topic over the following days. It became clear to me that Storey was himself curious to know why the proposal for PILOT might have been unsuccessful, and thought I might gain some insight. Over the course of discussions and email exchanges in the year that followed, some on-record and some not, I came to understand that for Storey, PILOT was not just a proposal that failed, it was *the* proposal that failed.

Without Storey, I would likely never have heard of PILOT. Anthropologists are perhaps (in general) more willing to talk about these coincidental moments of exchange than the STS scholars who have

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[87] (2018). "5th Workshop of the SCAR AAA." Astronomy and Astrophysics from Antarctica Retrieved 26 July, 2021, from https://www.astronomy.scar.org/meetings/5th-workshop-scar-aaa/.

written about failure.[88] Finding out about failures (or potential failures) is not simple, because they live only in institutional and individual memory. The history of Australian space science has not forgotten this bold Antarctic telescope so much as it never took notice in the first place. Among the bureaucracy of funding cycles, national priorities, and shifting institutional memory, PILOT may have been lost. And yet, once you know what to look for, echoes and shadows of PILOT appear everywhere. In the Decadal Plan for Australian Astronomy 2006-2015 for example, the peak document for astronomy planning in Australia at the time, PILOT is described as a project "of considerable long-term significance".[89] However, this assessment is undermined by the final section of the report, which is written in an imagined future (2020), and which reads like a eulogy.

> *Meanwhile, on the dry, cold highlands of the Australian Antarctic Territory, the world's first fully cryogenic optical and infrared telescope, PILOT, is closing up at the end of its last six-month-long night of observing. Amongst its achievements was the detailed study in 2011 of weather patterns on Mars and Titan that re-ignited the debate about life in our solar system. But the pace of development in astronomy is rapid, and PILOT is now being closed, as larger and even more powerful telescopes take its place.*[90]

What economic, structural, and social elements might have combined in such a way that PILOT appears a *fait accompli* in the Decadal Plan before disappearing almost without trace? In this chapter I present a pre-history of the PILOT proposal, which explains the context within which the idea of an Australian Antarctic telescope arose, before moving on to a detailed account of precisely what this telescope proposal suggested.

Having drawn my attention to PILOT initially, Storey's contribution to my research became both invaluable and complicated. On the one hand, he had (and has) an extensive knowledge of the particulars surrounding PILOT. He was on the editing committee for the Decadal Plan and led the team that proposed PILOT for funding. He was also more than happy to offer me information, provide photographs (some of which I have included), answer questions and speak to me in detail about his memories of the factors surrounding PILOT. This research would not have been possible without his cooperation and enthusiasm. On the other hand, he was (and is) undoubtedly interested in the outcomes of this research, from a personal standpoint as well as an intellectual one. Further, it became clear as I spoke to a wider circle of other people who knew about PILOT that the Australian astronomy community was not, is not, and perhaps never has been, united in its opinions as to what projects should and should not be funded, and that there are underlying professional tensions (if not outright animosity) between institutions and individuals, which undoubtedly coloured the way in which they approached my questions and my research study generally.

Educational Sociologist and Anthropologist Martin Forsey has written about the challenges of conducting an ethnographic study within a divided community with multiple conflicting interests and standpoints.[91] He embedded himself at a school in Western Australia during 1998-1999, which coincided with a period of serious conflict between staff, the principal, and the broader school

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[88] See, for example, the candid accounts of awkward entanglements during anthropological studies in Hume, L. and J. Mulcock (2004). Anthropologists in the Field: Cases in Participant Observation, Columbia University Press.

[89] Boyle, B., C. Tinney, C. Jenkins, E. Sadler and J. Storey (2005). New Horizons: a Decadal Plan for Australian Astronomy 2006 – 2015, National Committee for Astronomy of the Australian Academy of Science. **1**.

[90] Ibid. p. 46.

[91] Forsey, M. (2004). "He's Not a Spy; He's One of Us": Ethnographic Positioning in a Middle-Class Setting. Anthropologists in the Field: Cases in Participant Observation. L. Hume and J. Mulcock, Columbia University Press.

community. Forsey writes with candour, describing how, as an outsider, he was seen as an ally, threat, and even a tool by various individuals and groups, and the ways that this changed over time. More relevantly for my research, Forsey explains how his research itself was politicised by the community, and how cooperation from individuals, especially the school's principal, varied over time in ways that impacted his research methodology and findings, and also led to a personal feeling of "discomfort" at being in a space that was "socially awkward" for Forsey as a researcher.[92] For Forsey, citing Mulcock,[93]

> *… being caught in anthropologically and socially awkward interstitial spaces is potentially useful and productive, particularly if the researcher is seeking to document and understand a configuration of conflicting perspectives.*[94]

While my research is not an ethnography of the sort Forsey was carrying out, his description of feeling concerned that he was being "lured too far into" the viewpoints of those he was researching resonates.[95] While Forsey chose to 'follow the conflict', I instead thought of Storey's perspective as a starting point. I sought out other senior individuals who had, at the time, been seeking funding for other telescopes, as well as people who had worked on all aspects of the PILOT proposal and surrounding work, at every level of seniority from a then-PhD student upwards.[96] After numerous informal conversations, Storey and I sat down for our first formal interview in May 2020. Asked about PILOT, Storey's account of how he came to propose this telescope characterised the project as the culmination of a lifelong 'flirtation' with space. His narrative framing began with his childhood memories of Sputnik. He presented himself as a curious mind with an interest in engineering who was not particularly academically diligent in undergraduate years, but who managed to find himself in the right places at the right times. Storey credits a fortuitous moment as leading to his postdoctoral studies under the famed American physicist Charles "Charlie" Townes.[97]

Storey also described early encounters with dual-use technology (technology that has military as well as civil applications) in the form of his Honours year in ionospheric physics, which he described as being "all the rage back in the '60s and '70s because prior to communications satellites, and optical fibres, short wave radio communication was the way you talked from one side of the world to the other, and it had … It was very significant [for] commercial, political, and military reasons of course". The thread of identifying value in military-developed technology for civil science returned in Storey's account of working with Townes, which he called "an extraordinary privilege".

> *Charlie Townes was very high up in various advisory committees, and so he had a finger on the pulse as to what was happening, in the technological sense. And I guess it was that project that really taught me how getting hold of this technology, as soon as the military will*

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[92] Ibid. See also Colic-Peisker, V. Ibid.Doing Ethnography in "One's Own Ethnic Community": The Experience of an Awkward Insider.

[93] Mulcock, J. (2001). "Ethnography in Awkward Spaces: An Anthropology of Cultural Borrowing." Practicing Anthropology **23**(1): 38-42.

[94] Forsey, M. (2004). "He's Not a Spy; He's One of Us": Ethnographic Positioning in a Middle-Class Setting. Anthropologists in the Field: Cases in Participant Observation. L. Hume and J. Mulcock, Columbia University Press. p. 66.

[95] Ibid. p. 66.

[96] Warwick Anderson uses this kind of approach to great effect in his account of the scientific 'discovery' of Kuru. See Anderson, W. (2008). The Collectors of Lost Souls: Turning Kuru Scientists into Whitemen. Baltimore, Maryland Johns Hopkins University Press.

[97] For more on Townes, see Finkbeiner, A. (2015). Charles Hard Townes Made Things Happen. The Last Word On Nothing, Independent.; Finkbeiner, A. (2006). The Jasons: The Secret History of Science's Postwar Elite, Penguin Publishing Group.

> *let out of their clutches, gives you an incredible advantage in astronomy. Because astronomers, with all their pretensions, they don't actually invent terribly sophisticated things. They just use the sophisticated things that someone else invented, in a novel way.*

After a stint on NASA's Kuiper Airborne Observatory, Storey returned to Australia to work as a staff scientist at the Anglo-Australian Observatory (AAO), and then became an academic at the University of New South Wales (UNSW) from 1982, working on projects that he described as being focused on improving the technology available to astronomers working in non-military contexts. Many of these projects involved trying to find and utilise locations with low atmospheric interference, generally by placing instruments (some of which Storey told me had come from the US military) at high altitude.

Storey also spoke about his broader engagement with the Australian Space Industry, explaining that while at UNSW, he became involved with Academy of Science committees on how Australia could develop a larger space industry. But he felt his efforts with these committees were never very successful. As he put it, "despite some compelling arguments as to why Australia should be taking space seriously, this is mid-1980s, it was clear that the government had no intention of getting serious". To illustrate his point, Storey told me "we produced a report called 'Ready to Launch', I think was the name of it. And I subtitled it [unofficially] 'ready to launch, but out to lunch'".[98]

2.2.2 Australian Antarctic Astronomy: getting started

The framing Storey provided gave context to his growing interest in Antarctic astronomy, which came at the same time as he gained significant influence over research directions due to his position as Chair of Physics at UNSW and "pretty much gave up" on efforts to kickstart a viable domestic space industry. Storey named three influential individuals as being partly responsible for his turn towards a field that he described as being still mainly theoretical at the time. Storey's former postdoc supervisor Townes had written a paper suggesting that the high, dry, cold mountain peaks of Antarctica might be a good alternative to the Kuiper Airborne Observatory.[99] Peter Gillingham, a noted astronomer then working as an engineer at the AAO, had suggested that the Antarctic atmosphere was suitable for highly precise measurements of star positions.[100] Finally, Storey cites the visit of American physicist Martin Pomerantz to Australia as sparking an interest in Antarctic astronomy.[101]

In their 2005 account of the history of Antarctic astrophysics, astronomer Michael Burton and astrophysicists Balthasar Indermuehle and Sarah Maddison also cite Pomerantz and Gillingham as being key figures in catalysing Australia's involvement. Their narrative begins with Pomerantz's visit in 1986, which led to Gillingham's presentation on the subject in 1989. According to their history, the discussions that followed Gillingham's talk led to agreement that Australia should join international efforts to establish an observatory at Dome A, the highest point in Antarctica, which then prompted international engagement with a team of French scientists led by Jean Vernin, of the University of Nice, and the US team doing astronomy work at South Pole. In 1994, Burton, then

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[98] (1988). Ready for Launch: a discussion paper on space science in Australia. Canberra, Australian Academy of Science.

[99] The paper Storey was likely referring to was Townes, C. H. and G. Melnick (1990). "Atmospheric Transmission in the Far-Infrared at the South Pole and Astronomical Applications." Publications of the Astronomical Society of the Pacific **102**(649): 357-367.

[100] Storey may have been remembering Gillingham, P. R. (1992). "Super Seeing from the Australian Antarctic Territory?" ANARE Research Notes **88**: 290-292.

[101] Pomeranz's visit is also related in Burton, M. "The Evolving Science Case for a large Optical – Infrared Telescope in Antarctica." Journal and Proceedings of the Royal Society of New South Wales **145**(443-444): 2-18. p. 4.

working under Storey at UNSW, took some experimental equipment to South Pole station, and UNSW and ANU formed JACARA, the Joint Australian Centre for Astrophysical Research in Antarctica.[102]

Storey's account adds valuable colour to the series of events listed by Indermuehle, Burton, and Maddison. It was shortly after Storey's interest in Antarctic astronomy was piqued that he remembers hiring Burton to work at UNSW. Storey explained to me that he hired Burton partially because Burton expressed an interest in Antarctic astronomy (which Storey was now actively pursuing as a research focus), and partially because he was "a hard-core paper writer". The third core team member was Michael Ashley. Thus, Storey communicated to me a mature version of the enthusiastic but academically "less than stellar" student he'd been: a visionary, strategic leader of a team. He was impatient with the process of producing research papers, but aware of the need to do so.

Storey again invoked the 'right place and the right time' framing in explaining to me that both he and Burton knew an astronomer called Al Harper who was at the University of Chicago, and was working with the US Antarctic Program. Once again, the facts and dates as described by Storey align with the history written by Indermuehle, Burton, and Maddison, but the way Storey frames it is as a lesson in taking advantage of useful relationships and serendipitous funding opportunities.

As Storey recalls it, the US Antarctic Program received a large amount of funding to establish a Centre for Astrophysical Research in Antarctica (CARA).[103] They were "looking for ways to spend this money and how to do international collaborations", and "somehow we got the idea" of doing measurements of sky brightness at the South Pole. They found (as might be expected) that the sky was significantly darker at the South Pole than it was anywhere else on Earth. Not only was the science looking promising, but Storey also described the collaboration between UNSW and Harper's team as "a marriage made in heaven", because Australia's academic calendar made it easier for the UNSW team to go to Antarctica over the summer months than it was for the Americans.

Storey also spoke warmly of the human elements of the collaboration, keen to communicate how important these relationships, and the culture at South Pole more generally, were to the success of their work.

> *… working with the US, at the South Pole, was just a dream. They were, and still are, completely welcoming. We were … People flew their own flags. There was always an Australian flag on our staff. There was a Bavarian flag flowing over one of the experiments. And as you know there are the 12 flags of the nations who initially signed the Antarctic Treaty. It is fabulously international, and you arrive there … No one says to you "are you an Australian or a what?" You're just a human being. And it is almost outrageously international. In that you just stop feeling like you belong to a nation. You are just part of this community of mankind. Which is just a wonderful, wonderful feeling.*

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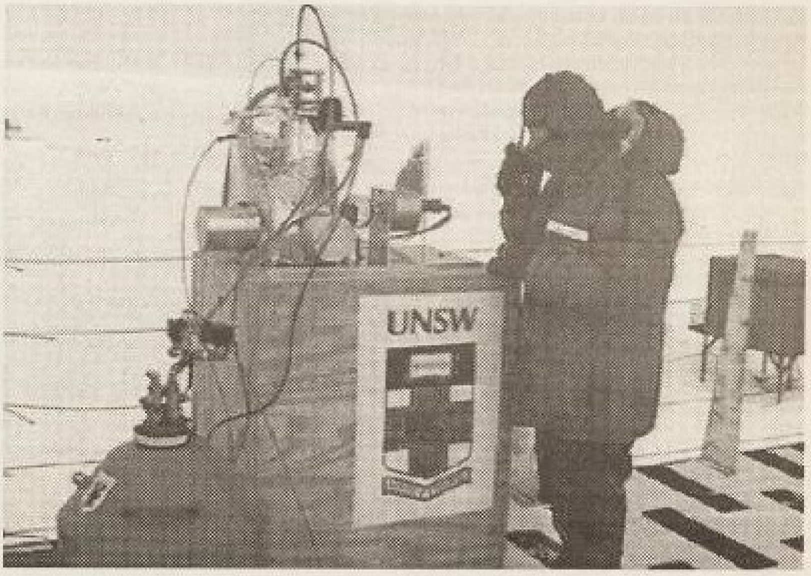
[102] Indermuehle, B. T., M. G. Burton and S. T. Maddison (2005). "The History of Astrophysics in Antarctica." Publications of the Astronomical Society of Australia **22**(2): 73-90. p. 77. Pomeranz's visit is also related in Burton, M. "The Evolving Science Case for a large Optical – Infrared Telescope in Antarctica." Journal and Proceedings of the Royal Society of New South Wales **145**(443-444): 2-18. p. 4.

[103] For more detail on the formation of CARA, see Indermuehle, B. T., M. G. Burton and S. T. Maddison (2005). "The History of Astrophysics in Antarctica." Publications of the Astronomical Society of Australia **22**(2): 73-90. p. 76.

Quoted in an article published in 1996 by UNSW newsletter *Uniken*, Burton echoed Storey's sentiments around the value of both the scientific research being conducted and the international collaboration occurring in Antarctica — "it's a most remarkable place to visit".[104]



Professor Storey working to fix the Infra-Red Photometer Spectrometer experiment at the South Pole to gather data for his deep space research. Photo: Audio Visual Unit

Figure 4 — Storey at South Pole in 1996.[105]

But as Storey explained, humans are themselves expensive technologies to maintain in Antarctica over the long, cold winters, and he and his colleagues needed a way to keep experiments running without a caretaker. The need to solve this problem was the impetus behind the development by Storey and his team of a remote observatory power source called AASTO (Automated Astronomical Site Testing Observatory). The AASTO was a modification of the AGO (Automated Geophysical Observatory) which was developed by the US National Science Foundation in collaboration with the Lockheed Missiles and Space Company in the 1980s.[106] Storey and Burton got access to an AGO by signing the 1994 MOU (Memorandum of Understanding) between UNSW and ANU which established JACARA (Joint Australian Centre for Astrophysical Research in Antarctica).[107] JACARA, with the approval of ANU and UNSW, purchased an AGO from Lockheed Missiles and Space Co, and, "with revised specifications and upgraded performance, this seventh 'AGO' becomes an Automated Astronomical Site Testing Observatory, or AASTO".[108] The key capabilities of the AASTO were that, once installed in Antarctica, it was self-powered, self-heating, and had minimal environmental impact. But perhaps the greatest environmental mitigant was that the AASTO did not require a

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[104] (1996). Searching For the Hidden Universe. Uniken. Sydney, UNSW**:** 3.

[105] Ibid.

[106] Storey, J. W. V., M. C. B. Ashley and M. G. Burton (1996). "An Automated Astrophysical Observatory for Antarctica." Publications of the Astronomical Society of Australia **13**(1): 35-38.

[107] Ibid. p. 3.

[108] Ibid. p. 3. Also referenced in McGuire, R. (1994). UNSW Astronomers Pull Secrets From the Stars: Antarctic plateau may be the ultimate observatory. Uniken. Sydney, UNSW**:** 6.

human presence to operate. It could run independently for 12 months at a time with “an absolute minimum of disturbance to the environment”.[109]

South Pole was not the only place Storey was interested in as a potential astronomy site. There were two other locations that captured his, and other astronomers’, attention: Dome C and Dome A. Both were at higher altitude, and therefore offered potentially better seeing (the technical term for the measurement of atmospheric disturbance that affects image clarity), than South Pole. With this in mind, the team proposed an Australian telescope for the Antarctic plateau as early as 2000, based on data from the AASTO at the South Pole.[110] The 8-metre telescope they envisioned “if constructed, would yield performance that would be unrivalled until the advent of the NGST [Next Generation Space Telescope]”.[111] A steppingstone towards such an observatory would be a 2-metre infrared telescope on the Antarctic plateau. The team suggested that such a telescope could be named the Douglas Mawson Telescope (DMT),[112] a name that “builds upon the scientific legacy and tradition that Australia has established in Antarctica and provides a springboard for further involvement in major international facilities in the coming decades”.[113] Presenting data from their efforts at South Pole, the team noted at the time that France and Italy were building a new scientific station (‘Concordia’) at Dome C, which had the dual advantage of offering (probably) even better seeing than South Pole, and falling within the Australian Antarctic Territory.[114]

In 2001, Jon Lawrence, an astronomer who had recently completed his PhD at Macquarie University, joined the UNSW team to work on the proposal for the DMT.[115] Lawrence found the UNSW astronomy team via a web search for a group doing “interesting” things in the field of astronomy and physics. After speaking to Storey, Burton and Ashley and deciding that “these guys at UNSW were a good fit”, Lawrence successfully applied for a fellowship from the Australian Research Council (ARC) to work on “something called the Douglas Mawson Telescope”. When I spoke to Lawrence in early 2021, his memory of specifics around PILOT was as hazy as one might expect after 20 years. I got the sense that while, for Storey, PILOT was *the* project, for Lawrence it was one of many projects, and the attraction for him was the adventure of doing Antarctic astronomy more generally.

> *… it just sounded pretty cool, you know? Pretty interesting. These guys were going down there to this pretty extreme place trying to build these remote instruments, and particularly there’s a challenge at Dome C, it’s so remote and so cold, the environmental conditions are pretty amazing, and so it’s a level of difficulty in terms of engineering that just brought a whole lot of challenges. I guess that’s part of what I found interesting about it, and the opportunity to go there of course was a strong driver at the time, but also there was the motivation, all of the reasons why it was a good place to build a telescope, I think I kind of got on board with all of that.*

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[109] Storey, J. W. V., M. C. B. Ashley and M. G. Burton (1996). "An Automated Astrophysical Observatory for Antarctica." Publications of the Astronomical Society of Australia **13**(1): 35-38. p. 36.

[110] Storey, J. W. V., M. C. B. Ashley, M. G. Burton and J. S. Lawrence (2005). "Automated Site Testing from Antarctica." European Astronomical Society Publications Series **14**(Dome C Astronomy and Astrophysics Meeting): 7-12.

[111] Burton, M. G., J. W. V. Storey and M. C. B. Ashley (2001). "Science Goals for Antarctic Infrared Telescopes." Publications of the Astronomical Society of Australia **18**: 158-165. p. 158.

[112] Ibid. p. 164.

[113] Ibid. p. 164.

[114] Ibid. p. 165.

[115] Lawrence, J. (2021). Research Interview. HREC 2020/145. A. Handmer.

As time progressed, Dome C emerged as the best location for a combination of scientific and social reasons. The main apparent scientific benefit Dome C had over South Pole was a thinner layer of atmospheric turbulence. Whereas the turbulence at South Pole would interfere with the quality of observations that any telescope could make up to about 200 metres, Dome C was clear from about 30 metres above the surface of the ice, and had a comparatively benign climate, even over winter. But without hard data, the UNSW team would not be able to attract funding to build a telescope there, and before they could think about data, they had to find a way of getting their equipment there.

Storey had been working on plans to site-test the domes for some years at this point. In 1996, even before AASTO had been deployed at South Pole, Burton, Ashley, and Storey put out a paper in collaboration with individuals from ANU, CSIRO, and the Australian Antarctic Division announcing JACARA's plans to place an AASTO at Dome Circe (Dome C) and Dome Argus (Dome A) by the end of the century. Using logistics support from the US National Science Foundation (NSF), their plan was to use a "ski-equipped LC130 aircraft" to deploy an AASTO "to the South Pole at the end of 1997, to Dome C at the end of 1998, and to Dome A at the end of 1999", with the intention of settling on a site to build an international observatory by 2000.[116]

In their 1996 paper, the JACARA team noted that there were plans by France and Italy at the time to establish a permanent base at Dome C (Concordia), and that the deployment of an AASTO at this site could be of mutual benefit.[117] Concordia, the station at Dome C, was first established in 1996 as a joint French and Italian summer camp to support the EPICA (European Project for Ice Coring in Antarctica) ice-core drilling project.[118] Its high altitude made the area ideal for extracting ice cores that could be used to construct climate records over hundreds of thousands of years. But there were also political reasons for establishing a more permanent base at Dome C. The site had been a location for cooperation between France and Italy, via their respective Antarctic programs, since 1993.[119] According to Storey, the base was a way for France and Italy to overcome nationalistic "rivalry". Dome C, sitting halfway between French coastal station of Dumont d'Urville and the Italian coastal station Mario Zucchelli (then 'Terra Nova Bay'),[120] was the ideal location for a join-run base. Storey remembers that the plan from the leader of the Concordia project, Mario Zucchelli, was for Concordia to "be an international station to which all the world's scientists would come, and it would show that the Europeans could do [at Concordia] what Americans could do [at South Pole], but better".

The plans to expand Concordia were key to JACARA's ambitions since the Australian team would need a place to stay while conducting site testing. To do so, they needed to be invited by the leaders of Concordia. At this time, the UNSW team was already collaborating at South Pole with a team of astronomers from the University of Nice. As Storey tells it, this collaborative relationship came about not as a result of planning, but good luck. After the Greenpeace vessel *Rainbow Warrior* was sunk in Auckland Harbour by French intelligence services in 1985, and following disagreements over nuclear testing at Mururoa Atoll, France and Australia engaged in diplomatic efforts to, as Storey put it,

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[116] Burton, M., M. Ashley, J. Storey, M. Dopita, A. Lancon, J. Mould, P. Wood, P. Hall and M. Duldig (1996). "JACARA's Plans." Publications of the Astronomical Society of Australia **13**(1): 33-34.

[117] Ibid. p. 34.

[118] Dargaurd, G. (2000, 14/02/2020). "Concordia, Antarctica." Retrieved 10/08/2021, from https://www.gdargaud.net/Antarctica/Concordia.html.

[119] (2021). "Concordia Station." Retrieved 10/08/2021, from https://institut-polaire.fr/en/antarctica/concordia-station/.

[120] Ibid.

"rebuild these wounds", and foster goodwill. One such project that came about was a collaborative French-Australian Astronomy program. Storey, appointed to the Australian panel, used the opportunity to solidify a working relationship with his University of Nice counterparts on site testing at South Pole.

Storey was therefore well-placed to hear about plans for the Dome C location, already flagged as a place of interest. This is one of the rare instances in our discussions that Storey admits to acting strategically. Having decided that Concordia was a base in need of a good science case, JACARA needed to persuade the teams who were actually in charge of setting the scientific agenda for the station that they should put astronomy on their list, and that the Australians were the people to help them do it. Storey and a fellow member of JACARA, Michael Dopita, went to a conference in Siena that they knew the key team members from the Concordia project would also be attending. At the conference, Storey and Dopita "did a kind of hard sell" on the idea that they should collaborate on doing astronomy at Concordia.

Another link came through one of Storey's PhD students, Paolo Calise, an astronomer who had spent some time at Terra Nova Bay, another Italian Antarctic station, and who knew Mario Zucchelli, then the director of the Italian Antarctic Program. Paolo introduced Storey to Zucchelli, and the two had common ground in that they had both spent some time at South Pole. Storey feels that it was the relationship with Mario Zucchelli (pictured in Figure 8) in particular that smoothed the way for the UNSW team to stay at Concordia and continue to research Dome C. When I asked Storey why he thought Zucchelli was so supportive, he posited that having Australian scientists who had been conducting experiments at South Pole bring those experiments to Dome C may have been a way of showing that Dome C could be an international hub, just like South Pole. However, despite admitting to his active advocacy for astronomy at Dome C, and noting the politics at play behind the scenes, Storey was quick to add that he thinks it likely that people would have thought of doing astronomy there without his involvement, because "it's kind of the obvious thing to do".

Once they had secured interest from Concordia's leadership, JACARA had to tackle the second hurdle: how to get site testing equipment to Dome C. Storey felt that, once data had confirmed their theory that it was an ideal location for astronomy, "the French groups and the Italian groups would find it much easier to get funding to build their telescopes". However, while the desire to support Italian and French astronomy efforts was part of the narrative, JACARA was also keen to do so for their own research purposes, as evidenced by their 1996 paper which announced plans to deploy an AASTO to Dome C by the year 1999.[121] In this early planning stage, astronomy at Dome C was being framed and reframed by individuals and groups to fit their respective narrative needs, invariably with the end goal of securing funding in order to build a telescope.

The preference of the UNSW team was to transport the existing AASTO equipment from the South Pole to Dome C, where it could continue to take measurements and to characterise the site. South Pole no longer had a use for the AASTO, and Storey preferred the idea of re-using it at Dome C than "dumping it out in the middle of the snow somewhere". Their plan, published in their 1996 paper, was that the NSF would fly the heavy equipment to Dome C along with Storey and the team. The NSF had the resources and logistics support necessary to transport heavy equipment, and the US Antarctic Program had previously been very supportive of JACARA's activities at South Pole. However, JACARA encountered a problem: the NSF did not want to fly the AASTO to Dome C.

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[121] Burton, M., M. Ashley, J. Storey, M. Dopita, A. Lancon, J. Mould, P. Wood, P. Hall and M. Duldig (1996). "JACARA's Plans." Publications of the Astronomical Society of Australia **13**(1): 33-34.

According to Storey, the problem was not with JACARA or the relationship, but with the NSF's attitude to Dome C.

> *… the Americans had been there previously, and crashed a Hercules there. An old Hercules. And they managed to get those people out, and I don't think anyone was hurt. And so the Americans flew in a new Hercules, to get some of the gear off the old Hercules, and they crashed that too. And so Dome C had a rather bad reputation amongst the Americans. Almost a … Some people almost described it as kind of a curse. That, it was like Dome C was haunted … There was no rational reason, but they just didn't want to fly aircraft are there anymore.*

2.2.3 Australians at Dome C 2002-2004

Having gained initial interest in the idea of doing astronomy at Dome C, the Australian team now worked to embed themselves, technologically and socially, at Concordia. In addition to producing data to justify the scientific case for an observatory at the site, the cooperative efforts in Antarctica between individuals during the early years in PILOT's development (starting with the logistic support JACARA received from both the French and Italian Antarctic programs, as well as the Australian Antarctic division) also catalysed the idea that PILOT should be an international facility, and a platform for further scientific cooperation. In the wake of the NSF's refusal to fly them into Dome C, Storey, Jon Lawrence, and Storey's PhD student Tony Travouillon managed to get themselves and their instruments a spot on the French ship ('L'Astrolabe') which sailed from Hobart to Dumont d'Urville station. They would then travel to Dome C by Twin Otter. They arranged for the equipment that was too heavy to fly in to be transported from Dumont d'Urville to Dome C by traverse by the French Antarctic program.

Figure 5 — Arriving at Dome C by Twin Otter. This photograph shows the Italian / French team refuelling the aircraft. The cost of providing logistics support to the Australian team was considerable.[122]

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[122] Photograph provided by John Storey as additional material to supplement our research interviews: Storey, J. (2020). Research Interview 1 of 2. HREC 2020/145. A. Handmer.; Storey, J. (2020). Research Interview 2 of 2. HREC 2020/145. A. Handmer.

Storey was keen to emphasise that the French and Italian Antarctic teams provided exceptional hospitality and logistics support for the 2002-03 and 2003-04 seasons. Without support from the French and Italian teams at Dome C, the Australians could not have transported their equipment to the site.

> *We told the French and the Italians that [the equipment] weighs about a tonne. And they said, "make sure it's down in Hobart [at] a certain date, and we'll put it on the ship, take it to Dumont d'Urville, and then it goes on a tractor traverse and gets dragged 1,200 km across the snow to Dome C, and if you guys come in at such-and-such a date, you will be there when it arrives, and you can build it and get all working".*

Part of that equipment was a newly improved version of the AASTO. Now that JACARA would have to bring in new site-testing equipment from Australia, rather than re-deploying the South Pole equipment, the UNSW team took the opportunity to improve their design. Dome C's unique environmental and social factors shaped their technological design. Unlike the South Pole AASTO, which could be powered from the South Pole station (crewed year-round), Concordia Station was in use only as a summer base. The AASTO at Dome C had to be capable of generating its own power and of operating fully autonomously through winter.[123] Storey changed the external shell of the AASTO, custom-designing a curved "caterpillar" shape that would deflect snow through the winter (see Figures 6 and 8). The new design was called the AASTINO (Automated Astrophysical Site Testing International Observatory).

In a 2005 paper, Storey, Ashley, Burton, and Lawrence described the AASTINO's design:

> *The AASTINO laboratory was deployed to Dome C station in January 2003. This was well before the station was due for manned winter operation, necessitating a completely self-reliant system. The AASTINO structure […] consists of an igloo-shaped outer fibreglass casing with internal polyurethane insulation, and instrument ports on the roof (similar to the AASTO). The primary power source for the AASTINO is the WhisperGen 24 VDC engine, a co-generation system based on a small four-cylinder double-acting Stirling engine. Two complete fully independent engine systems are installed in the AASTINO for redundancy. Additionally, two solar panels are installed to reduce fuel consumption through the summer months. The AASTINO communicates via the low bandwidth Iridium satellite network. Similar to the AASTO a central supervisor computer controls all AASTINO systems.*[124]

It wasn't until late 2002 that Storey, Lawrence and Travouillon transported their AASTINO to Dome C, setting up the infrastructure necessary to run experiments that would (they hoped) show the superiority of Dome C as a telescope location.

Beside the French, Italian and Australian flags that Lawrence, Travouillon and Storey planted in the snow beside the AASTINO to symbolise the collaborative nature of the project, the Australian team added an American flag (see Figure 6). Storey explained that the US had agreed to provide an Iridium satellite link so that data could be retrieved from the AASTINO remotely over the winter. However, he recalls that political tensions at the time were high and that when they returned for the 2003-2004 season, the American flag had been removed.

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[123] Storey, J. W. V., M. C. B. Ashley, M. G. Burton and J. S. Lawrence (2005). "Automated Site Testing from Antarctica." European Astronomical Society Publications Series **14**(Dome C Astronomy and Astrophysics Meeting): 7-12. p. 8.

[124] Ibid. p. 8.

Figure 6 — The AASTINO in position, with flags — left to right: USA, France, Australia, Italy. When the Australian team returned the following year, the American flag had been removed.[125]

Storey's description of the early years of PILOT's development reflected his understanding of the multiple layers of international politics and diplomacy that were at play in the decision to turn Dome C into a permanent base, the formation of a French-Australian astronomy collaboration, and the removal of the American flag. However, Storey saw the core business of doing science as separate to politics, particularly in Antarctica which he saw as being immune to the "national ambition or superiority" which might exist elsewhere. When I asked him to elaborate on what made Antarctica apolitical in his view, he explained it was a combination of the sorts of people who go there, the knowledge that you are reliant on each other for survival, and the culture, which he saw as being "very much a commune".[126]

> *I think that knowledge of what you're doing is dangerous, that you are privileged to be there, and you very quickly gain a personal respect for the people you work with, because there are interesting people and they've all got a story to tell. On top of that they think countries just kind of become irrelevant. Who cares what is happening in America, or Australia, or China. We are here in Antarctica and at least for this moment in time, what's happening out there is just utterly unimportant. It has no effect on me.*

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[125] Photograph provided by John Storey as additional material to supplement our research interviews: Storey, J. (2020). Research Interview 1 of 2. HREC 2020/145. A. Handmer.; Storey, J. (2020). Research Interview 2 of 2. HREC 2020/145. A. Handmer.

[126] Communities of Antarctic scientists and their cooperation in the context of the unique international legal framework of Antarctica have themselves been the study of ethnographic research. See O'Reilly, J. (2017). The Technocratic Antarctic: An Ethnography of Scientific Expertise and Environmental Governance. Ithaca, Cornell University Press.; O'Reilly, J. and J. F. Salazar (2017). "Inhabiting the Antarctic." Polar Journal **7**(1): 9-25.

Lawrence, now a Professor at Macquarie University and the AAO,[127] also expressed to me his positive memories of the experience of living and working at Concordia over the summers he spent there. He likewise identified a strong sense of community and mutual respect.

> *Oh, it was the most marvellous thing, you know, I think I've ever done, it was amazing, just burned in your head, this memory of going there, this amazing place, and all … really, everyone down there was so friendly, wherever you went, whether it was the bases on the coast, or you know, on the boat down there, or in Dome C itself, yeah, it was just a real kind of environment of shared … you know, people shared responsibility of everything to look after each other, and to be respectful of each other, and also of recognising the kind of privilege of going there, and of the fact that people who were there were there for a reason, so, typically we'd work pretty hard when we were there and it would be a lot, you know, you'd be working 12, 16 hour days, whatever, particularly at the end where you're going to switch something on and then walk away, and no one is going to come back for another, 11 months, and you know, there was always time pressures and things breaking and whatever, having to sort of build things and problem shoot things on the fly. But yeah, so, yeah, it was an amazing experience.*

Travouillon and Storey fondly remember the cooking of the French Chef at Concordia at this time, Jean-Louis Duraffourg (pictured in Figure 7), as well as his sense of humour.[128] Storey told me of an elaborate, multi-year trick Duraffourg played on him. I paraphrase:

> When the UNSW team arrived at Concordia in 2002 there was a small cat litter tray in the corner of the dining room with a bowl beside it. Animals are prohibited in Antarctica, so Storey was scandalised and quietly asked Zucchelli whether there was a cat at the station. Zucchelli replied that the Chef, Jean-Louis, had insisted on bringing his cat to the station. Throughout their stay, the food in the bowl disappeared and droppings would appear in the litter tray. Storey was convinced that Jean-Louis did indeed have an illegal cat wandering the station.
>
> The following year when Storey returned with PhD student Anna Moore (now at ANU), the litter tray was gone. He asked Jean-Louis what had happened. Jean-Louis shook his head sadly. "Ah, it is terrible. We got very hungry over the winter and we had to eat the cat!" It was only later that Storey discovered that the whole thing had been an elaborate hoax, and that there had never been a cat at all. Jean-Louis had made fake cat food and fake droppings daily for almost two months, purely to fool the visiting Australians.

Curiously, Lawrence told me he has no memory of any cat at the station, real or hoax, but when I asked about Jean-Louis, Lawrence recalled that the chef prepared him a special birthday meal of snails one year, which had been brought into Dome C as part of Luis' cooking supplies. While clearly appreciative of the effort, Lawrence described the experience of eating these as "pretty gross".

The AASTINO was operational from January 2003.[129] The results from data collected over the 2003-2004 summer season, published in 2004 in *Nature*,[130] confirmed what JACARA had anticipated.

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[127] (2021). "Jon Lawrence, Professor, Australian Astronomical Optics." Profiles Retrieved 11/05/2021, from https://researchers.mq.edu.au/en/persons/jon-lawrence.

[128] Travouillon, T. (2020). Research Interview. HREC 2020/145. A. Handmer.

[129] Lawrence, J. S., M. C. B. Ashley, A. Tokovinin and T. Travouillon (2004). "Exceptional Astronomical Seeing Conditions Above Dome C in Antarctica." Nature **431**: 278–281. p. 279.

[130] Ibid.

Dome C had many of the natural benefits that the South Pole had, but with the improvement of higher altitude: less wind, clearer skies, and lower turbulence. By the end of the AASTINO's first year of operation, Storey and the team at UNSW had enough data to begin planning PILOT in earnest — a telescope that would make use of the exceptional seeing conditions they had identified, while resilient to the unique environmental conditions. The next step was to make a formal design and project proposal to secure the government funding necessary to build it.

Figure 7 — French chef at Dome C's Concordia station, Jean-Louis Duraffourg.[131]

Figure 8 — From left to right: Storey, Mario Zucchelli (Italian station leader, who was instrumental in his support of the Australian team's involvement at Dome C), Travouillon, and Lawrence.[132]

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[131] Photograph provided by John Storey as additional material to supplement our research interviews: Storey, J. (2020). Research Interview 1 of 2. HREC 2020/145. A. Handmer.; Storey, J. (2020). Research Interview 2 of 2. HREC 2020/145. A. Handmer.

[132] Photograph provided by John Storey as additional material to supplement our research interviews: Storey, J. (2020). Research Interview 1 of 2. HREC 2020/145. A. Handmer.; Storey, J. (2020). Research Interview 2 of 2. HREC 2020/145. A. Handmer.

Figure 9 — Left to right: Lawrence, Travouillon, the AASTINO engine, and Storey.[133]

Figure 10 — Skiing, Dome C style. The varying social cohesion between occupants of Concordia were an important part of PILOT's initial success, and subsequent problems.[134]

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[133] Photograph provided by John Storey as additional material to supplement our research interviews: Storey, J. (2020). Research Interview 1 of 2. HREC 2020/145. A. Handmer.; Storey, J. (2020). Research Interview 2 of 2. HREC 2020/145. A. Handmer.

[134] Photograph provided by John Storey as additional material to supplement our research interviews: Storey, J. (2020). Research Interview 1 of 2. HREC 2020/145. A. Handmer.; Storey, J. (2020). Research Interview 2 of 2. HREC 2020/145. A. Handmer.

2.3 The PILOT proposal

It … wasn't so much born, as it evolved.

John Storey, PILOT

2.3.1 Changing funding landscapes

Among the details of discussions, interviews, and research on PILOT's history, it is easy to lose sight of the many visions that underpinned the extraordinary idea to put a telescope at Dome C, a place that, until 2005, was inhospitable to human life outside of the summer months. Dome C is uniquely challenging as a location for anything, let alone as a potential site to operate and maintain precise, sensitive, and expensive equipment. JACARA's pitch for PILOT was that it would be a 'pathfinder' — a telescope that existed as a proof of concept that would attract interest for a bigger, more powerful telescope in future. PILOT's purpose was to demonstrate that Dome C was a great site for astronomy, and to catalyse international cooperation between astronomers in Antarctica. But so far, PILOT was just an idea, supported by some promising-looking data on seeing conditions. The team now needed to win funding to do a design study to work through key challenges and (ideally) produce a credible proposal.

In this section, I demonstrate how shifting funding structures and strategic priorities at a national level had influence over how the PILOT proposal developed. Australia's funding architecture for astronomy projects changed just as the PILOT team had the data and the publications necessary to make a serious bid for government funding. Suddenly, PILOT was caught between two very different processes: the Decadal Plan process, which was a mechanism by which the astronomy community engaged in long-term planning, and the newly announced 'National Collaborative Research Infrastructure Strategy' (NCRIS) process, which was about making immediate funding decisions shaped around national priorities. NCRIS was not the only source of funding for astronomy projects, but it was a significant structural change offering a non-trivial amount of funding alongside an entirely new governance process. The announcement in the 2004-2005 federal budget of the $542 million for NCRIS initially looked like a good fit for PILOT, because it offered the kind of money that would be needed for such an ambitious project. But a crucial difference from other grants and funding processes which was challenging for the PILOT team was that NCRIS required scientists to think in 'strategic' terms in a national context. NCRIS was asking Australian science to justify itself *politically.*

Thus, although NCRIS offered a substantial amount of money for big projects, it came with its own entirely new decision-making structure and process which was still being defined even as the team behind PILOT were shaping their plans for the telescope. Following the announcement of NCRIS, the Minister for Education, Science and Training, Brendan Nelson MP, appointed an Advisory Committee to determine how NCRIS, at this stage a policy and a line item on a budget, should be implemented.[135] This Committee was advised by four expert subcommittees, which advised on each of the four National Research Priorities. Following "extensive" consultations with the public and with the scientific community, the Committee submitted recommendations for how NCRIS should run to the Minister in July 2005, which the Minister accepted.[136] NCRIS identified priority capabilities, under which strategies, developed by independent, external facilitators, would be turned into "national

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[135] (2006). National Collaborative Research Infrastructure Strategy Strategic Roadmap. Australia, NCRIS Advisory Committee. p.3.

[136] Ibid. p. 3.

investment plans".[137] In practical terms, NCRIS was a new process by which Australia's government asked Australia's scientific community (including the astronomy community) to work together in field-segmented groups to decide what projects should be funded out of an allocated pot of money.

The new NCRIS process for how astronomers would identify priority projects to fund coincided with an existing process by which astronomers were already planning future projects: the Australian Astronomy Decadal Plan. Sitting on the Editorial Board of the Decadal Plan, Storey had a home-field advantage with this process. He understood the criteria — some explicit, some not — by which projects were judged. Under this pre-existing process, working groups produced reports which were submitted to the National Committee for Astronomy (NCA), who produced a Decadal Plan every 10 years, with a mid-term review every alternate decade. When the 2004-2005 budget was announced, the Decadal Plan process was already well underway, and due to conclude not long after the NCRIS Committee submitted their recommendations to the Minister. At that time, the NCA was chaired by Dr Brian Boyle, then Director of the Australian Telescope National Facility.[138]

As part of the NCRIS consultation process, the NCA collated the draft reports from the Decadal Plan working groups and submitted them to NCRIS.[139] The process was no doubt made easier by Boyle's dual role: he was simultaneously chair of the NCA and sat on one of the NCRIS subcommittees.[140] The report that the NCA prepared based on drafts from the Decadal Plan working groups does not name PILOT, but it unmistakably appears in this report, listed alongside other projects as the first stage in developing a "larger 8m (or greater) telescope" for Antarctica.[141] Following receipt of input from various stakeholders, the NCRIS Committee released the *National Collaborative Research Infrastructure Strategy Strategic Roadmap* in February 2006.[142] Astronomy occupied an important place in the Roadmap, which called it "one of Australia's highest impact sciences".[143] It went on to express that maintaining Australia's standing internationally in astronomy was important for encouraging public interest in science and "provides powerful evidence to the rest of the world of Australia's scientific and technological capacity".[144] Further, it argued that astronomical sciences could produce economic growth and "spin-off benefits" through "significant collaboration with industry".[145]

However, while the section of the Roadmap which outlined priority areas for NCRIS investment stated explicitly that it was "consistent with [the Decadal Plan]" (published November 2005), PILOT was not mentioned.[146] The three projects that made it into the Roadmap were additional support for the Anglo-Australian Observatory (AAO), delivery of the Square Kilometre Array (SKA) phase 1, and

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[137] (2008). "Overview of NCRIS." Australian Government, from https://web.archive.org/web/20091111233745/http:/ncris.innovation.gov.au/development/Pages/default.aspx.

[138] Boyle, B. J. (2005). Key capability requirements for Australian Astronomy (2006-15), National Committee for Astronomy.

[139] Ibid.

[140] (2006). National Collaborative Research Infrastructure Strategy Strategic Roadmap. Australia, NCRIS Advisory Committee. p. 66.

[141] Boyle, B. J. (2005). Key capability requirements for Australian Astronomy (2006-15), National Committee for Astronomy. p. 6.

[142] (2006). National Collaborative Research Infrastructure Strategy Strategic Roadmap. Australia, NCRIS Advisory Committee.

[143] Ibid. p. 35.

[144] Ibid. p. 35.

[145] Ibid. pp. 35-36.

[146] Ibid. p. 36.

access to time on an 8-metre telescope.[147] Thus, at this stage, PILOT had made it into the Decadal Plan, but the report that went to NCRIS, compiled from draft working group input to that same Decadal Plan, had not mentioned PILOT by name, and PILOT missed out on a mention in the Roadmap. The NCRIS process was still ongoing. Following the release of the Roadmap, Boyle put out a one-page process summary that named the end of May as the deadline for the first draft of investment proposals to be submitted to the NCA. The document names the same three projects listed in the Roadmap, noting that Matthew Colless, then Director of the AAO, and Michelle Storey, Australian SKA Planning Office Leader, would coordinate their projects' investment proposals.[148]

With this new deadline, John Storey and his colleagues had only a short time to develop a proposal. They began a series of discussions, meetings, and a 'Town Hall' on PILOT, in order to accelerate development on the project and take it from a vision supported by data to a viable project proposal. In May 2006, they completed a six-page document that laid out instrumentation, a summary of the science cases, and costing.[149] The document put on record for NCRIS that Storey and his team saw PILOT as a serious project. The team's work paid off. In the Spring of 2006, NCRIS released an *Investment Plan for Radio and Optical Astronom*y, also facilitated by Boyle.[150] PILOT was mentioned by name, with detailed accounts of science cases and funding requirements. With the first allocation of funds, PILOT received $1 million for a detailed design study.

By this time, PILOT had previously been pitched unsuccessfully at least twice. In 2001, the Douglas Mawson Telescope (DMT), an earlier manifestation of PILOT, had been rejected for funding by the Australian Government Major National Research Facility (MNRF) scheme. More recently, in 2005, PILOT had missed out on being included in the Australian Research Council (ARC)'s Centre of Excellence scheme.[151] Between late 2005 and late 2006 in particular, PILOT was shaped and reshaped to try to slip between ever-shifting goalposts. Not only did PILOT have to meet the new criteria, it also had to be different to the other proposals with which it was competing, and complement whichever proposals were most likely to 'get up'. There was a tension between the PILOT that was presented in the Decadal Plan, a proof-of-concept telescope that paved the way to doing serious Antarctic astronomy ('the pathfinder telescope'), and the PILOT that was pitched for NCRIS, a piece of national infrastructure that was integral to Australia's still-nebulous strategy ('the strategic option'). Thus, over the course of these various attempts to gain funding, descriptions of PILOT in pitch documents changed from a 2-metre 'proof-of-concept' scientific telescope to a strategic dual-use facility that could conduct observations that could otherwise only be done from space, as and carry out a number of potentially valuable strategic tasks: contribute to climate models, observe space debris, and monitor space weather.[152]

Another notable structural change to come out of the shifting funding landscape was the formation of a new peak body for astronomy in April 2007 — Astronomy Australia Limited (AAL).[153] Its purpose was purely to administrate the new funding mechanism, to contract with the Commonwealth to

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[147] Ibid. p. 36.

[148] Michelle Storey was (and still is) married to John Storey.

[149] Storey, J. (2006). "PILOT — Securing Australia's Long-term Future in Optical/IR Astronomy Through Antarctica " CSIRO.

[150] Boyle, B. J. (2006). Investment Plan for the Research Capability: Radio and Optical Astronomy, National Collaborative Research Infrastructure Strategy.

[151] Burton, M. (2012). "The Evolving Science Case for a Large Optical – Infrared Telescope in Antarctica." Journal and Proceedings of the Royal Society of New South Wales **145**(443 & 444): 2-18. pp. 9-11.

[152] Boyle, B. J. (2006). Draft Investment Plan for the Research Capability: Radio and Optical Astronomy (September 2006), National Collaborative Research Infrastructure Strategy. p. 24.

[153] Cole, M. (2007). Astronomy NCRIS: 2006/07 Progress Report, Astronomy Australia Limited. p. 2.

receive and distribute funds to all the research organisations and universities who put forward projects as part of this overarching Investment Plan.[154] In June 2007, the Australian Government's Department of Education, Science and Training contracted with AAL to enact the funding agreement that governed the provision and expenditure of NCRIS funds.[155] The process was long and complicated, because the funds had to be transferred through a series of agreements from the relevant Government fund to whichever institution had ownership of each project. Thus, the $1 million was initially granted to AAL, then subcontracted to the University of New South Wales (UNSW) on 27 August 2007.[156] In turn, UNSW subcontracted the AAO (at that time named the 'Anglo-Australian Observatory') to "carry out the technical design of the telescope and associated infrastructure".[157]

NCRIS funding also came with governance requirements, and part of the contract between AAL and UNSW stipulated the formation of the AAAAC — the Australian Antarctic Astronomy Advisory Committee — to advise "on PILOT and other Antarctic Astronomy developments".[158] The Committee was made up of 12 representatives from the various member organisations of AAL, including Storey, Boyle (who had been the NCRIS Facilitator) and Colless, and was chaired by Brett Biddington. At this point, PILOT had all the makings of a successful science project: a strong core team with a clear vision, government funding, and the backing of influential individuals. However, even as Storey and his colleagues at the AAO began to make decisions about PILOT's design, the decision-making process by which any future funding might be bestowed on the project was still under construction itself.

2.3.2 Phase A Study: technological considerations

PILOT, I think, right from the beginning was on top of a 30-metre tower

John Storey, PILOT

The process of PILOT's technological design reveals the influence of Australia's changing funding policies and processes and the political priorities that underpinned them. Originally, Storey had envisaged PILOT as a pathfinder telescope, which would prove that it was possible and pave the way for a better, more expensive telescope and scientific program to follow. Pathfinder-PILOT did not need to do world-beating science immediately, it just needed to prove that such science *could* be done from Dome C. In the development process, PILOT would assemble all the necessary elements for an extensive, long term international program: funding streams would have to be established, institutional contracts would be negotiated, international agreements would be formed, and logistics corridors would be created. But now that PILOT was being pitched as an NCRIS project, it had to stand on its own as a piece of national infrastructure that could deliver a strategic return on investment and, importantly, deliver great science too, because by competing in the NCRIS process, PILOT was now being weighed against far more established scientific programs. The Phase A study

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[154] Boyle, B. J. (2006). Investment Plan for the Research Capability: Radio and Optical Astronomy, National Collaborative Research Infrastructure Strategy. p. 6.

[155] (2007). Funding Agreement between the Commonwealth of Australia as represented by the Department of Education, Science and Training and Astronomy Australia Limited. Canberra, Australian Government Department of Education Science and Training, Innovation and Research Branch.

[156] (2007). Astronomy Australia Ltd NCRIS Subcontractor Agreement. Agreement between Astronomy Australia Ltd and The University of New South Wales.

[157] (2008). Annual Report of the Anglo-Australian Telescope Board, Anglo-Australian Observatory. p. 46.

[158] (2007). Astronomy Australia Annual Report 2007-2008, Astronomy Australia Limited. p. 2.

for PILOT therefore needed to both produce a credible design which could take advantage of (and justify) the choice of location at a scientific level and meet the government's political priorities of the day. It is from this point that my account of PILOT begins to make apparent those factors that played an important role in the decision of the ANSOC — the committee tasked with deciding where the NCRIS funds would go — to overlook PILOT in favour of other options. The key difficulty for the PILOT design team was that PILOT could not simultaneously be Storey's pathfinder and have a credible chance of being competitive in the NCRIS process. Both politically and scientifically, PILOT needed to be an end in itself, not a step in a long process.

The team behind PILOT had claimed in 2004 that "a telescope placed at Dome C would compete with one that is 2 to 3 times larger at the best mid-latitude observatories, and an interferometer based at this site could work on projects that would otherwise require a space mission".[159] When we spoke in 2020, Storey repeated that above the turbulent ground layer at Dome C, any telescope would be "practically in space as far as the image quality is concerned". For a pathfinder, the telescope only had to be good enough and large enough to show that observations could be made, and that they were of adequate quality to justify funding a larger, more expensive telescope. But to compete with the other projects in the NCRIS round, the PILOT team had to prove that the seeing offered by the Antarctic location could truly compete with a space telescope proposal, and to do that, their technical design had to present a telescope of sufficient quality to rival a space telescope. Storey explained that this meant, among other factors, that PILOT needed a mirror which was "better than any mirror that had been made before", and at the same time, the cost had to be kept to a minimum because the logistical costs of transporting the telescope to Antarctica and assembling it would be higher than those associated with a non-Antarctic project.

Tasked with designing a telescope that would somehow technologically embody these political and technological contradictions was the PILOT design study team, led by Storey, and made up of four team members from the AAO's Instrument Science Group. Most of the technical work was done by Saunders, who was still working at the AAO under Colless. In July 2008, Saunders, Gillingham, McGrath and Haynes from the AAO, and Storey and Lawrence from UNSW, presented the completed PILOT Design Study to the Astronomical Society of Australia.[160] Their presentation repeated many of the points made in the 2004 paper covering the initial science case: Antarctica has excellent seeing, low cloud, and low precipitable water vapour.[161] It presents Dome C as a well-characterised site, already home to a major station (Concordia) and within the Australian Antarctic Territory.[162] Additional detail included the proposed instrumentation: a fast optical camera, a wide-field mid-infrared camera, a wide-field near-infrared camera, and a wide-field optical camera.[163]

The presentation also addressed some of the unique environmental challenges posed by the Antarctic landscape. One key issue was the surface layer of atmospheric turbulence, which the design study proposed solving by placing the telescope on a tower.[164] While the idea of a tower was conceptually sound, there were significant challenges to building a structure capable of holding the weight of the telescope and keeping it relatively steady. Any infrastructure also had to be resilient

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[159] Lawrence, J. S., M. C. B. Ashley, A. Tokovinin and T. Travouillon (2004). "Exceptional Astronomical Seeing Conditions Above Dome C in Antarctica." Nature **431**: 278–281. p. 279.

[160] Saunders, W., P. Gillingham, A. McGrath, R. Haynes, J. Storey and J. Lawrence (2008). The PILOT Design Study. Meeting of the Astronomical Society of Australia.

[161] Ibid. slide 2.

[162] Ibid. slides 3-4.

[163] Ibid. slide 14.

[164] Ibid. slide 8.

enough to withstand extremely low temperatures and the vicissitudes of Antarctic winter without the possibility of doing any *ad hoc* repairs or maintenance for most of the year.[165]

Storey, speaking in 2020, was keen to impart to me that the challenge would have been totally achievable.

> *Various critics, and one always has critics, said "how on earth are you going to put a tower in the snow", and we'd got in touch with people who build ski lifts, and we asked them how hard it was to build a 30 m tower in the snow, and they basically said that they do that before breakfast every day, and that this is not an issue.*

One reason Storey was so confident was that he had seen a tower built at Dome C already, by an American team over the same 2002-2003 season that Storey, Lawrence and Travouillon were installing the AASTINO. While the tower may not have been strong or stable enough to support a 2.5 metre telescope, it did support the UNSW team, who were invited to climb it (see Figures 11 and 12). My impression talking to Storey and reading through the design study documentation was this tower represented for him a silver bullet of sorts: proof that a tower could be built at Dome C. A photograph of the American tower appeared on the right-hand side of the slide outlining 'Antarctic Challenges' in the presentation of their design study (Figure 13), and on the slide directly following, the right-hand panel was occupied by a computer-generated mock-up of PILOT perched atop a wide, but recognisably similar, tower (Figure 11).[166]

But opinions differed, even in 2020 as I carried out research interviews, as to whether such a tower was ever feasible. Matthew Colless, who represented AAO on the AAAAC and was also working on a rival proposal for Australia's involvement in the Giant Magellan Telescope Design and Development Phase (GMT DDP) at this time, was sceptical about meeting such a technical challenge when we spoke in mid-2020.[167]

> *Even if you get above the ground layer and can get that good imaging, you've got to figure out how to make your tower stand up under the accumulated weight of ice, from all that moisture laden air, at the ground level that is building up on that superstructure.*

Biddington, who chaired the AAAAC, still believes that PILOT could have worked, but raised the tower as the one "technical challenge that had to be convincingly stated". As he stated in our interview, adding a laugh at the complexity of the problem, "there was one thing that was problematic, and that was that the damned telescope had to be on a hundred-foot-high mast", built on "frozen water", which meant that even if such a tower could be safely constructed, there was a risk of "wobble". Although work was carried out to solve this challenge, and Biddington readily admits that he is not a "technologist", he remains unsure that the team "ever actually satisfied that requirement". Even Lawrence, who worked on the design study, expressed some uncertainty when we spoke as to whether the tower would have worked, although he was quick to add that his uncertainty was because PILOT only got as far as Phase A, and solving such technical challenges would have been done in Phase B.

For Storey, convincing his audience that PILOT was possible — whether his audience was the Astronomical Society of Australia in 2008, or a PhD student investigating PILOT's history in 2020 — rested in some significant way on proving that the tower could be, or *could have been*, built.

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[165] Ibid. slide 7.

[166] Ibid. slides 7-8.

[167] Colless, M. (2020). Research Interview. HREC 2020/145. A. Handmer.

Additional photographs of this tower were among those that Storey shared to assist my research. But compared to most observatories, which are housed in domes perched on top of mountains, the idea of a telescope that came with its own mountain was evidently not as intuitive for everyone as it was to Storey, who by this time had been working with site-testing instruments at the top of such structures for years.

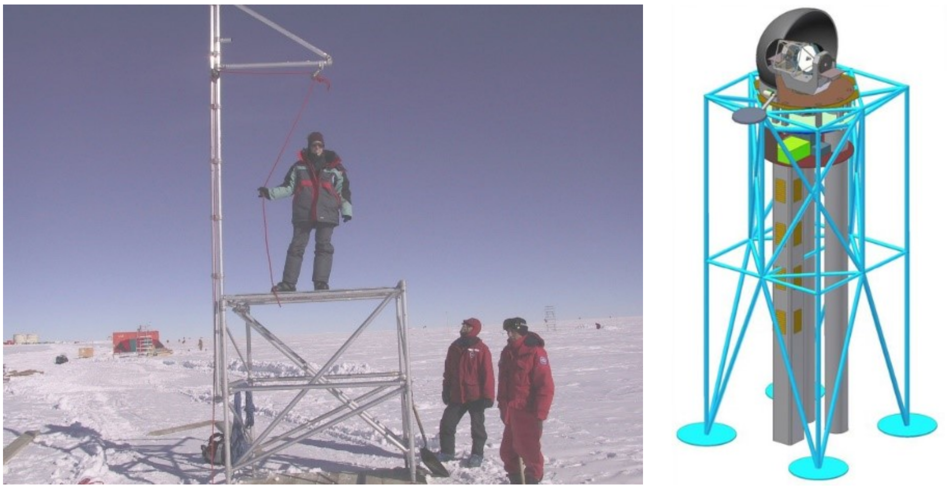

Figure 11 — Storey's photograph of the early stages of construction of the American tower (left) bears a notable resemblance to the computer-generated design image of PILOT that appeared in the 2008 Design Study (right).[168]

Figure 12 — The UNSW team climb the tower. Travouillon is pictured here giving a 'thumbs-up'.[169]

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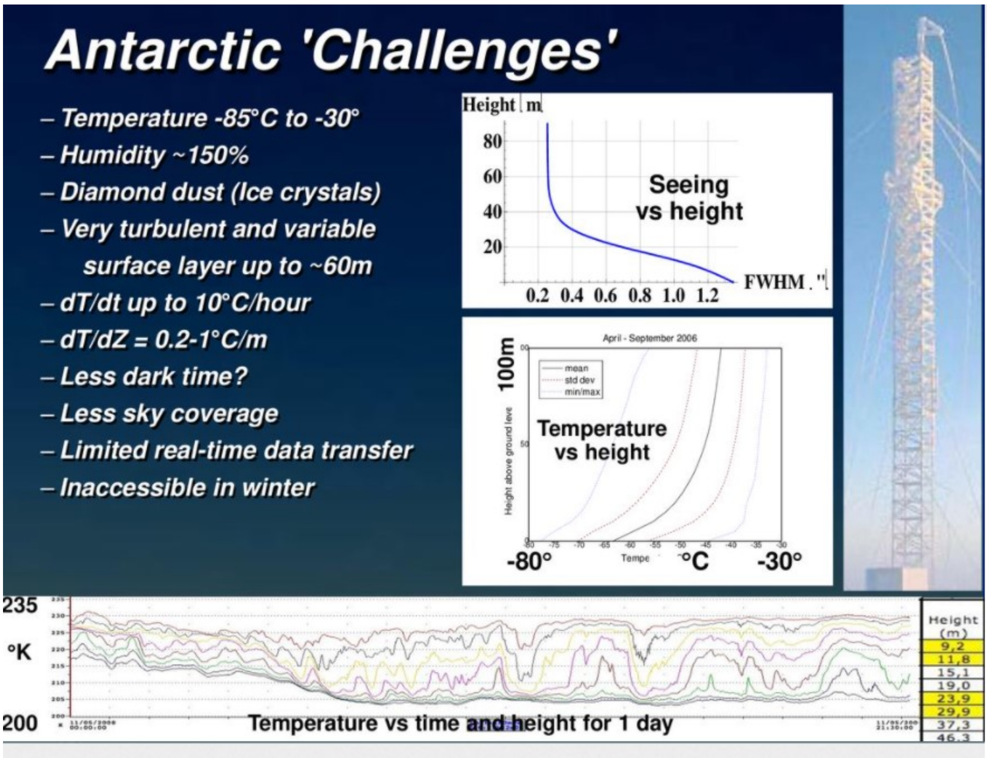
[168] Saunders, W., P. Gillingham, A. McGrath, R. Haynes, J. Storey and J. Lawrence (2008). The PILOT Design Study. Meeting of the Astronomical Society of Australia. slide. 8.

[169] Photograph provided by John Storey as additional material to supplement our research interviews: Storey, J. (2020). Research Interview 1 of 2. HREC 2020/145. A. Handmer.; Storey, J. (2020). Research Interview 2 of 2. HREC 2020/145. A. Handmer.



Antarctic 'Challenges'

- Temperature -85°C to -30°
- Humidity ~150%
- Diamond dust (Ice crystals)
- Very turbulent and variable surface layer up to ~60m
- dT/dt up to 10°C/hour
- dT/dZ = 0.2-1°C/m
- Less dark time?
- Less sky coverage
- Limited real-time data transfer
- Inaccessible in winter

Figure 13 — The completed tower that Storey and Travouillon climbed at Dome C, as it appeared the Design Study presentation, juxtaposed with a list of Antarctica's climatic challenges, many of which the team suggested the tower would solve.[170]

Once the equipment had been lofted above the 30 metres of turbulent ground layer on a purpose-built tower, the next challenge was constructing a telescope that was of sufficient quality to make the most of the location. The design study team decided on a 2.5-metre-class telescope, and explained in their presentation that this decision was a compromise between making a telescope large enough to do "world-beating science" and buying a mirror small enough to be ion-polished and conveniently shipped.[171] In addition, at 2.5 metres the mirror could foreseeably be manufactured by any one of a number of vendors, reducing the cost, risk and timeframes.[172] But having decided on the kind of mirror which would hopefully deliver seeing that rivalled space telescopes, the team then had to figure out how to keep it clear and functioning properly with only six weeks of access each summer. One significant problem unique to Antarctica was the combination of low temperature and high humidity. This was flagged as a challenge in the design study,[173] but Saunders added more detail when we spoke, explaining that because Antarctica's air is so clean, "there's nothing for frost to form on, except your nice shiny mirror".[174]

Additionally, there was the wind shake on the tower and the risk of diamond dust (ground-level clouds of ice crystals) to contend with. While temperatures would be low year-round, they would fluctuate with the seasons, and the temperature of the telescope at the top of the tower would be different to the temperature of any air flowing through from lower down. For at least 10 months of the year PILOT had to fend for itself without human intervention. It wasn't possible to send someone

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[170] Saunders, W., P. Gillingham, A. McGrath, R. Haynes, J. Storey and J. Lawrence (2008). The PILOT Design Study. Meeting of the Astronomical Society of Australia.
[171] Ibid. slide 6.
[172] Ibid. slide 6.
[173] Ibid. slide 7.
[174] Saunders, W. (2020). Research Interview. HREC 2020/145. A. Handmer.

up a ladder to defrost the mirror. The PILOT design team had to figure out an automatic and failsafe way to keep the mirror clear year-round. The ingenious solution (at least in theory) was to “put [the] telescope in [a] dome” with the “aperture as small as possible”, and to “ventilate continuously with dry air warmed to the same temperature as the aperture”.[175] If air from a lower altitude could be brought to a higher altitude (lowering its relative humidity) and pushed quickly past the mirror, and there was a minimal temperature differential between the air and the mirror, there would be less opportunity for the water in the air to adhere to it. The air would be warmed with the heat already created by the power supply, so there was no requirement for additional power to perform this step.

With some (if not all) of the design challenges solved in theory, and decisions made about PILOT’s size and specifications, the team now had to form a large team of people and organisations capable of actually building it.

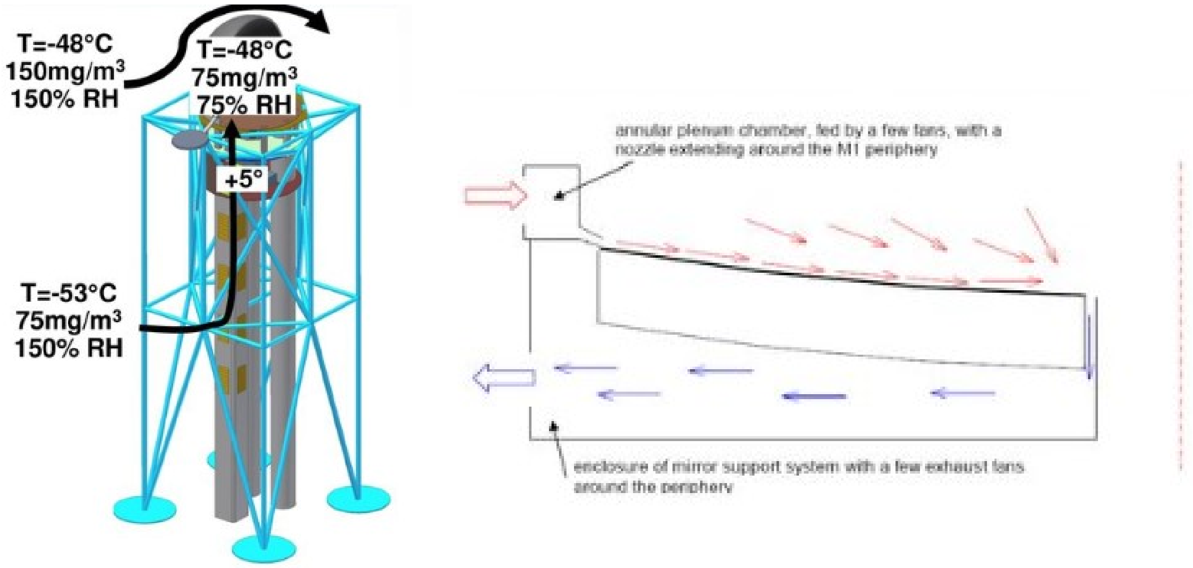

Figure 14 — PILOT’s design attempted to solve, for the first time, issues unique to the environmental conditions of the high Antarctic plateau, including the risk of frost on the mirror. ***Left****: PILOT airflow diagram.* ***Right****: PILOT mirror diagram.*[176]

2.3.3 Collective imaginings and divergent narratives

One of the challenges that emerges when writing a history of something that did *not* happen, based on available documented sources and human memory, is that at times the narratives diverge significantly. Such a divergence occurred when I asked interview participants about PILOT’s dual-use history. While the ‘facts’ of the various retellings I heard aligned, the interpretation of those facts, and the weight of significance each person placed on particular aspects, differed considerably. In turn, some individuals denied that PILOT had ever been considered in more than purely scientific terms, and others suggested that PILOT’s ‘other’ uses, particularly its ability to observe objects in polar orbit, were a significant part of its conceptualisation and design. In this section, I present several different perspectives and juxtapose them to draw out, analytically, what the key variations

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[175] Saunders, W., P. Gillingham, A. McGrath, R. Haynes, J. Storey and J. Lawrence (2008). The PILOT Design Study. Meeting of the Astronomical Society of Australia. slide 10.

[176] Ibid. slide 10.

are. I then propose that the rhetorical differences in the ways the narratives are told by different individuals go part of the way towards explaining how such a variety of visions for PILOT came about.

While the Instrument Science Group from AAO were able to team up with Storey and Lawrence to do a design study on PILOT, both the AAO and UNSW lacked the capability to build it, and instead the next stage in the process saw Storey meeting with private sector companies to request quotes for building the various components that would make up PILOT. For the high-quality mirror, for example, Storey spoke to AMOS, a Belgian company who build telescopes and space instruments, and SAGEM, who in Storey's words "do a lot of military stuff". Everyone I interviewed was aware that PILOT's proposal foresaw it being built by companies that routinely filled both civil and military contracts, but their views differed as to why this was important.

I asked Travouillon about the implications of having companies with military branches or associations working as part of a bid for public funding to build a scientific telescope like PILOT, curious as to whether their non-civil activities (usually alluded to obliquely on their websites with terms such as 'space security', or the catch-all euphemism 'space industry') might in some way tarnish the image of a civil project. Travouillon pointed out to me (very politely) that such a view is totally naive: contracting telescopes out to the private sector is routine, and most space telescopes are built by players like Lockheed Martin or Northrup Grumman: "big companies who have money to spend".[177] Big projects like PILOT require expertise, large teams, and specialist equipment that universities generally can't provide. Travouillon explained:

> *… for small projects scientists tend to do it themselves, sometimes they have the capability to do it themselves. For example, we are building a half metre telescope right now in our labs, so we can do it on that scale. But as soon as you wish for a certain volume, then you need larger teams, a wider set of expertise and so you need to involve industry. And it's never seen as a bad thing … I mean it's perfectly normal, it's perfectly acceptable.*

Travouillon noted that at this time he was no longer working on PILOT or Antarctic astronomy so he was not aware of the specific circumstances that led to various companies becoming the preferred providers for PILOT. However, in a general sense, he explained that in choosing who you award a contract to for a civil science project, "you want a company that may also help you [in] lobbying for the money".

> *… if you take, for example, the case in the US of those larger space telescopes, you know that Lockheed Martin has a lot of lobbying power, in the US politics. So … but definitely it works for them if they say, "we're going to be building this and these companies are going to be building it" and then they can all push together, you know the lobbying stuff and the science stuff, the industry side, jobs, jobs, jobs … So everything is quite lined up.*

While Travouillon highlighted the functional role that a contracted company could play in a telescope bid at a corporate level, Storey, in his telling, privileged the importance of partnering with individuals who he felt understood the project at a technological level, wherever they worked. The company the design team chose to build the telescope itself was Electro Optic Systems (EOS). EOS bills itself as "a leading Australian technology company operating in the space and defence

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[177] On interplay between science and the military-industrial complex, see DeVorkin, D. H. (1992). Science with a Vengeance: how the military created the US space sciences after World War II. New York, Springer-Verlag.; Galison, P. (1997). Image and Logic: a Material Culture of Microphysics. Chicago, University of Chicago Press. Tyson, N. G. and A. Lang (2018). Accessory to War: The Unspoken Alliance Between Astrophysics and the Military, W. W. Norton.

markets".[178] EOS was founded in 1983, headed up by Ben Greene, whose previous career involved working with space tracking technologies in partnership with the US. Instead of telling me about EOS's considerable lobbying power in Australia, Storey explained that his preference for EOS was based on his working relationship with Craig Smith. Storey told me he had known Smith since he was a PhD student and had spent a summer with him at South Pole in 1996,[179] by which time Smith was a Senior Research Fellow in the School of Physics at the Australian Defence Force Academy (ADFA).[180] Smith went to work for EOS in 1998 and became the Chief Executive Officer (CEO) of EOS Space Systems in 2003.[181] It was, of course, important that EOS had the capacity to build PILOT, but what mattered in Storey's telling of the narrative was that he felt that Smith understood the appeal of Antarctica as a location to do astronomy, because he had actually been there.

> *Craig had, at least, a strong interest in Antarctica. He knew it was possible to actually work down there; make measurements, do good science. And he and I after that time talked quite a lot about what we could do in Antarctica.*

It also mattered to Storey that he and Smith could "just chat, very openly about things". He acknowledged that he might have gone with EOS anyway, because they were one of few Australian companies capable of building PILOT, but that "it wouldn't have been as easy working with EOS if it hadn't been for Craig".

Here I have juxtaposed two very different approaches to building a project team that emerged from interviewing two people who worked in the same sector, and (briefly) on the same project. Storey highlighted to me the importance of selecting a group of individuals who shared his vision, and who (he felt) *believed* that PILOT was possible — he was interested in *conceptual* alignment. He also, once again, pointed to the element of chance in the narrative — he'd happened to run into Smith at South Pole, and now Smith worked at EOS, and was in a position to build a telescope for him. Travouillon, on the other hand, drew out for me the importance of *structural* alignment. For Travouillon, what was important about choosing EOS was the lobbying power that such a company could bring to the team when operating within funding structures that increasingly asked scientists to make a case for their projects. Both perspectives have their merits: Storey was right in identifying that, having claimed that Antarctic astronomy could be as good as space-based telescopes,[182] but with no actual telescope data from Dome C to prove it, he needed people in the room who could argue strongly because they themselves agreed it was possible.

But what Travouillon saw, and Storey perhaps missed, was that the landscape itself was shifting. It wasn't enough to make a good science case; PILOT needed to be backed by a *business* case which made it clear that PILOT was a good investment for Australia: scientifically, commercially, *and* strategically. What's interesting about the deal that Storey worked out with EOS was that it is clear that EOS's quote for PILOT was, as Storey confirmed for me, "a good deal. An extremely good deal". Storey recalled that EOS would supply the telescope "at a very reasonable price, one or two million dollars, I think", and another company (AMOS or SAGEM) would supply the high-quality mirror at

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[178] (2020). "About Us." EOS Retrieved 14 December 2020, from https://www.eos-aus.com/about-us/.

[179] Smith, C. H. and D. A. Harper (1998). "Mid-Infrared Sky Brightness Site Testing at the South Pole." Publications of the Astronomical Society of the Pacific **110**: 747-753. p. 1. See also a 1993 mention in Uniken of Smith working on Antarctic Astronomy with Aitken: (1993). Astronomers Set Sights on Antarctica. Uniken. Sydney, UNSW**:** 1-2.

[180] (2020). "About Us." EOS Retrieved 14 December 2020, from https://www.eos-aus.com/about-us/.

[181] Ibid.

[182] Lawrence, J. S., M. C. B. Ashley, A. Tokovinin and T. Travouillon (2004). "Exceptional Astronomical Seeing Conditions Above Dome C in Antarctica." Nature **431**: 278–281. p. 279.

"another half-million on top of that". In addition, Smith assisted Storey by putting together "excellent tender documents" to assist with the PILOT team's quests to win the funding to build the telescope. While Storey informed me that the details of a commercial deal "was never discussed", he thought the reason EOS were able to offer the PILOT team such a "good deal" was likely that EOS expected to be able to analyse the data they got back in commercially useful ways.

Whether or not Storey had knowingly formed a strong lobbying team by engaging with EOS, he had done so anyway. At least at this early stage, EOS seemed very interested in making PILOT happen, and while Storey's tales of South Pole camaraderie went some of the way towards explaining Smith's helpful attitude, it did not explain why Greene was also willing to back the idea, and why EOS were able to offer such competitive rates for the build. When I put this to Storey, he acknowledged that he had wondered whether EOS were building similar telescopes "as part of their military activities, and the astronomy thing was just kind of a sideline". He was quick to add that he had "the good grace" not to bring his suspicions up with Smith. Nonetheless, Storey told me that he thought EOS were interested in PILOT as a dual-use facility, able to do astronomical science while also collecting information about space debris.

Space debris, sometimes called orbital debris or space junk, is the name given to non-functioning objects or component parts that remain in orbit. NASA estimates that there are currently more than 500,000 pieces of space debris in orbit.[183] Once an object is propelled beyond the atmosphere it stays there, and it's very hard to remove. From time to time, objects collide with others, creating clouds of smaller debris particles. The risk of collision poses a technical, financial, and political challenge to space operations.[184] The practice of tracking and characterising objects in orbit is called Space Situational Awareness (SSA).

As Storey explained to me, "Dome C is particularly favourable for looking for space junk - at least, this is the argument they put to me - because it has long periods of twilight". Storey recalls that Smith and he "talked very openly about the dual-use capability, and the fact that if you're just looking at this stuff, then that's a purely passive activity, so it's not a military thing, which would clearly raise eyebrows". But Storey was quick to reinforce for me that Smith's interest in PILOT was because of the science potential, regardless of any dual-use benefit having a telescope at Dome C may or may not have offered EOS.

> *Craig I think, he had a personal interest in getting a telescope into Antarctica. I think he really … he was still, at least partly, an astronomer at heart. And he could see that this would actually be hugely good for astronomy.*

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[183] (2013, 7/8/2017). "Space Debris and Human Spacecraft."   Retrieved 28 September, 2018, from https://www.nasa.gov/mission_pages/station/news/orbital_debris.html. The status of space debris as 'junk' or 'rubbish' is itself contested. A/Prof. Alice Gorman from Flinders University has done significant work in cataloguing items of space debris as 'cultural heritage' (Gorman, A. (2005). The Archaeology of Orbital Space. Melbourne, RMIT University. p. 17). She argues that, for future generations, the debris left by early voyagers to space may be the only record they have by which to understand the methods and technology that first took humans into space. Gorman advocates for an approach to debris remediation that preserves important items in situ. Some debris may therefore be of interest for historical and archaeological reasons, quite apart from any Space Traffic Management or military SSA requirement.

[184] In 1978 Kessler and Cour-Palais theorised that if there were enough objects in an orbit, a chance collision would set off a reactionary cascade of collisions, leading to a 'soup' of particles that would preclude human uses of that orbit for satellites or other purposes until such a time as they naturally decayed (possibly several hundred years). The effect is called 'Kessler Syndrome'. Kessler, D. J. and B. G. Cour-Palais (1978). "Collision Frequency of Artificial Satellites: The Creation of a Debris Belt " Journal of Geophysical Research **83**(A6): 2637-2646.

It became clear in the course of my research that while imaging space debris might have been just one of a number of science cases for PILOT, it became increasingly central to PILOT's success. Initially, I had assumed that the scientific purpose of a telescope would be determined before the telescope was imagined into being, and that technological choices would flow from that initial decision. The astronomers I interviewed patiently explained to me that building a telescope is about first building a case for funding, and that you need as many 'science cases' as possible, because, as Travouillon pointed out, more science cases mean more institutions and individuals who can see their "pet interest" being satisfied by a project. Travouillon also noted that science cases need to be "agile", because observatories take so long to build that the original scientific justification may become obsolete before the telescope sees first light.

Saunders was tasked with developing sciences cases for PILOT, and explained that the key challenge was that there was no "killer app".

> *It wasn't trivial to find science cases that were unique to PILOT. We did find some, and one or two of them were very important; but it wasn't, it wasn't - what do you call it - a no-brainer. I mean it wasn't obvious [that] something you could do from there you couldn't do from anywhere else.*

Colless, who provided the initial money that got PILOT to the stage of pitching for NCRIS Phase A study funding, was sceptical about what he called the Antarctic astronomy "Kool-Aid" that Ashley and Storey "were selling", but he did say that he agreed with Saunders that Antarctic astronomy filled a niche in widefield high resolution imaging, which could be used for cosmology-related science such as gravitational lensing. The problem for PILOT was that this was something that could already be done, and probably better, by other telescopes in development, including GMT. Saunders told me that the planned Euclid satellite, for example, with its "absolutely exquisite" infrared sensitivity, "would have done most of the things that PILOT wanted to do, ah, um, and better than PILOT". James Webb Space Telescope (JWST), according to Saunders, would have been "a thousand times more sensitive than, than PILOT could ever be".

The one area where PILOT was distinct from any other telescope was that it could image debris (and satellites) in a polar orbit. Storey explained:

> *… if you launch a satellite, let's say from China, to name a country at random, and that satellite is going into a polar orbit heading south, comes up over Australia and then Antarctica and it gets up, gets into … as it's coming over Antarctica it is up to its altitude. It's got rid of all its casings, all its rocket casings, and all that crap. And so it's your first real chance to get a look at it, and see what it is.*

Storey recollected speaking "somewhat circumspectly" about the idea of using PILOT for national security purposes, as distinct from debris tracking, with the chair of the Australian Antarctic Astronomy Advisory Committee (AAAAC), Biddington. Biddington, who now runs his own consultancy, has a background in foreign affairs and intelligence.[185] His long career, first with the Department of Foreign Affairs and Trade (DFAT) and then in the Royal Australian Air Force (RAAF), and then with CISCO Systems, has resulted in an extensive network of relationships at senior levels.

Storey recalled sitting on the Australian Telescope Steering Committee, "a government appointed committee to basically advise the government on whether the Australian radio telescopes were

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[185] Biddington, B. (2020). Research Interview 1 of 2. HREC 2020/145. A. Handmer.

doing a good job", which Biddington chaired, in the late 1990s. According to Storey, Biddington felt that imaging objects in this polar orbit "would be a really useful thing to be able to do". Saunders, responsible for designing the camera that could image objects overhead, was clearly not aware of any conversations that Storey and Biddington might have been having in the background. He admitted to me, somewhat sheepishly, that "to be honest, you know, we weren't interested in space debris at all. It was simply a realisation that we could do something that had a much better chance of attracting funding than astronomy". He went on to add that PILOT would only see space debris in polar orbits, and that this was a limitation to a science case. Meanwhile, in the NCRIS Investment Plan, the team had started to position PILOT's dual-use debris-tracking capabilities creating "important opportunities for private sector co-investment".[186] The document also suggests that PILOT itself could be used purely for debris tracking "once astronomers have moved on to larger telescopes".[187]

At Storey tells it, PILOT was taking shape as early as the late 1990s as an idea that was actively sculpted by individuals familiar with dual-use interests. But my interview with Biddington on the subject suggests that Storey's perception of the extent to which PILOT might be a dual-use facility might be overstated. Biddington explained that any alternate use for PILOT was incidental.

> *Did we ever think about using it for other things? And the answer is, not really. I don't recall any, what I'll call 'systematic or systemic conversation' about uses that we could put this to in terms of satellite tracking or satellite detection. We always knew that, of course, any sensor close to the pole was going to capture a lot of the LEO traffic. But it was never thought of as … it was not at the front of our minds.*

I pushed Biddington on this point, because the words "systemic conversation" point to a nuance that is key to unpacking how it was that PILOT could have been so many things to so many people at once. What makes a conversation 'systemic'? I asked Biddington to clarify whether PILOT had ever been thought about in national security terms, specifically from the perspective of looking at satellites or objects in orbit.

> *I'm sure that's … look, I'm sure that's the case. And in fact I would have been one of those who was saying things like, 'look, for example, if you put something here that's an optical telescope, you can see satellites, and you can see potentially space debris if it's illuminated by the sun'. But, of course, what we didn't do was complete the sentence, and say, 'and how you would use this, would be to get it off Antarctica' — and how do you do that? Interesting question, — 'and then ingest it into extant things like the Space Surveillance Network or an Australian network or whatever'. We simply, if you like, said there is a theoretical possibility that a satellite in Antarc — not a satellite, a telescope — in Antarctica, can do this.*

To Biddington, then, the defining factor is not whether a thought is had, or an idea communicated, but whether a 'sentence is completed' — which, he claims, wasn't the case for PILOT. He went on to explain that while it was "obvious, in a sense" that PILOT could have a role to play in national security activities, the team did not approach Defence with a serious proposal on the topic, primarily because, according to Biddington, there would not have been any interest or understanding from individuals working there at the time of the potential utility of such a facility.

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[186] Boyle, B. J. (2006). Draft Investment Plan for the Research Capability: Radio and Optical Astronomy (September 2006), National Collaborative Research Infrastructure Strategy. p. 21.

[187] Ibid. p. 21.

> *You know, we didn't go and talk to Defence, and say 'would you be interested if we were to … in co-investing, with a view to getting data about … from this telescope in Antarctica'. If we'd have had that conversation with Defence in 2009, 10, 11, 12, whatever the years were, we'd have [been] laughed at. The people in Defence wouldn't have known what to do with that.*

While the substance of what Storey and Biddington told me lined up (PILOT as a scientific telescope which a reasonable person might imagine having other uses), there was a small divergence that emerged in how they expressed the narrative. Storey drew an outline for me around that which he did not know, provided me with what evidence he saw as pertinent, and invited me to draw my own conclusions as to what might have been going on behind the scenes. Biddington, on the other hand, painted for me a picture of what 'behind the scenes' looked like, gesturing to the structural realities which made systemic conversation unlikely, and shared his recollections of what was *not* done. Thus, Storey's 'I don't know' invites speculation, while Biddington's 'I don't recall' shuts it down.

This divergence is important. It goes part of the way to explaining why there were at least two equally valid ways to think of PILOT, and why each person involved in the PILOT program picked their own variation on each of these themes as their 'truth'.

First, for those who wished to 'complete the sentence', the ingredients of a genuinely dual-use facility were plainly obvious. Here was a telescope that everybody involved knew would be built at a very competitive rate by EOS, a company that was building many such 2.4 metre telescopes for non-civil uses, with a mirror made by SAGEM, a company that did "a lot of military stuff". It was public knowledge that the telescope had, as the chair of its only committee (whether or not the AAAAC were across the financial or operational details of the proposal), a person who had spent his career in national security and intelligence. It was written into the design study that PILOT would be built at the top of a tall tower in an inaccessible location which just happened to be optimal for spying on satellites in polar orbits, and would be equipped with a camera purpose-designed to image objects in low-earth-orbit. It was plainly written in the NCRIS investment plan that in future, PILOT might transition to being a dedicated debris-tracking facility, operated by the private sector.

Second, for those like Lawrence, Saunders, and Travouillon, who didn't have quite enough information to 'complete the sentence', or had the information but preferred to let the sentence hang, PILOT was just another science telescope, to be built by the most capable company in Australia at the time, with a mirror supplied by the best supplier of telescope mirrors for the task. It was public knowledge that the committee of respected experts in their field who were advising on the project included Biddington, someone with enthusiasm for Antarctic astronomy and a wealth of experience in radio astronomy. It made absolute sense that PILOT should be built at the best possible location as scientifically and logistically determined, which happened to be at the top of a tall tower at Dome C. The fact that it might look at objects in polar orbits, debris or otherwise, was incidental and of little scientific interest, but it might be a handy way of differentiating PILOT from other telescope proposals and maybe catching the eye of someone in government who had sway. PILOT was never intended to be a long-term observatory, it was more of a short-term pathfinder project, so who cared what it was used for once it had served its purpose? If saying it might be useful as a debris-tracking station helped get PILOT across the line, so much the better. It wouldn't affect the science that could be done.

Thus I completely believe that Saunders, who actually designed the camera that would be used to image debris and wrote the space debris science case, was as totally unaware that 'debris' might read to some as 'active satellite' as he seemed to be when I interviewed him. When I pushed him to explain why the concept of 'debris' might attract more funding, Saunders invited me to form my own conclusions, or ‘complete my own sentence’, based on my knowledge of the space sector, and national interest in tracking capabilities.

> *… probably you know more about it than I do, and it was all a long time ago, but clearly, all space agencies are very interested in debris because they don't want to lose their satellite, so, it seemed reasonable, it seemed plausible that if, that if Australia could offer something unique in terms of space debris, then the Australian space agencies might take an interest. But really you're at the limit of what I know about this, you know, you’ll know much more about these things than I do.*

At the time the Phase A study was happening, Travouillon had finished his PhD and was working at Caltech. Nonetheless, Travouillon had been at Dome C, and had worked closely with Storey on formulating initial plans for PILOT. I also knew, from our discussions, that Travouillon was more open than Storey when talking about dual-use and astronomy in general. But of PILOT, Travouillon said, “this telescope was not meant to have any dual-use. I mean it was an astronomy telescope”. He justified EOS’s interest as being purely about their proven ability to build Australian telescopes. He pointed out that they had built Sky Mapper at Siding Springs, and Outrigger for Keck, and PILOT would have been “just another contract to build an astronomy case telescope. And nothing else”. Travouillon acknowledged that potential uses of telescopes for surveillance or other activities is something that astronomers think about now, “as leverage for adding value for funding”, but in his view this is a new thing: “back then, you know, there was nothing other than astronomy”.

Travouillon feels that this change is not universal, but indicative of the direction of change, and that while he is not totally happy about what Colless might capture with the term ‘space industrial complex’, he acknowledges its utility.

> *… still to this day when I mention this to some colleagues, that are, you know, of an older generation, when I say … When I talk about SSA, Space Situational Awareness, they look at me like I’m making something up on the spot.*
>
> *I mean they’re still thinking in the old … And the way they’re thinking is the way it should be thought of, to be honest. I mean we should not basically merge all these things together … But sometimes you know if you can use leverage to push your project over the line, I think you shouldn’t shy away from it … completely. I think, if you can find support in … The way I see it is I just ‘add a science case’. To go back to that word I used earlier, I mean to me we were going to track debris with a telescope made for astronomy, to me that’s just an additional science case. It’s just we are doing one extra thing with the data. We are not really making it harder for astronomy, we’re not losing anything from the astronomy side. We’re just adding support. We are building partnership. We are adding leverage at the funding level.*

Lawrence, who worked on the PILOT design study, offered an equivocal statement, initially saying that PILOT had no dual-use component, but then going on to clarify that what he meant by this was that there was no specifically *military* use planned for PILOT.

> *Oh, you mean some military use. No. Certainly, we … there was some … no, …no. We … we talked about … various other … yeah, and looking back to the requirements that we developed for the whole project, we … there was never anything about satellites or about any military use or dual use. There were some different types of science cases like looking at asteroids or planets or whatever, that were slightly different from the rest of it, but we never really investigated that or … we were never really driving the project based on that.*

Even in Storey's case, while it was obvious that he knew more about possible other interests in PILOT than anybody else, he kept drawing my attention back to his perception of Smith's belief in Antarctic astronomy as his preferred 'end to the sentence'. For the others who worked on the design study, if they suspected that PILOT might be useful to EOS or others for more than taking photos of debris, they, like Storey, had the "good grace" not to ask, and completed the sentence in their own minds in whatever way they saw fit.

Ultimately, it is impossible to know for certain whether or not PILOT was ever under serious consideration as a national security asset. Biddington's explanation — that it was an obvious option, that it would have been useful, but that was never seriously pursued because social and structural elements that were needed were not present at the time — is plausible, and not inconsistent with other accounts. More importantly, as interesting as it is to form conspiracy theories about PILOT, it does not matter because the telescope was never built. Rather, what is important to acknowledge is the diversity of ways in which those involved in the project thought about its potential dual-uses, and their attitude towards such an idea. There are three threads of interest here that will return in Chapter 3. First, even in the early 2000s, it was entirely normal to everybody involved that an astronomy telescope would be built by military contractors, whether EOS, Lockheed Martin, Raytheon, or anyone else. Second, that space debris surveillance acted as a convenient fig leaf that, if only in theory, enabled civil and military, and academic and private sector interests to converge in a useful and productive way without those involved having to think too hard about any moral implications of the project. And third, just as the phrase 'dual-use' meant something different to everyone, the fact that PILOT was a collective imagining formed of sentences that were never completed enabled each individual to draw their own conclusions, and tell their own narrative, to themselves, to each other, and to me.

Chapter 3: PILOT rejected

> *I mean in astronomy, like every other science, there is more projects than there is money for, so there are winners and losers, things could have gone a different way …*
>
> **Tony Travouillon, PILOT & SERC**

The Phase A study complete, the PILOT proposal was now subject to the scrutiny of the Astronomy NCRIS Strategic Options Committee (ANSOC). From the 1st to the 5th of September 2008 this panel, appointed to the task by Astronomy Australia Ltd., heard and reviewed proposals from the astronomy community to decide how to allocate the NCRIS funds at their disposal. PILOT, requesting almost $7 million to undertake a Phase B study, was competing with two other major projects for funding: the ‘Purchase of Additional Access to 8-m Class Telescopes’, for just over $2 million, and the ‘Purchase of a 5% Australian national share in the Design and Development Phase (DDP) of the Giant Magellan Telescope (GMT) Project’, for the sum of just under $3 million.[188] Their report recommended that the 8m Telescopes and GMT share should be funded, and PILOT should not. It was at this moment that, in Biddington’s words, “those who were assessing our bid and the relative merits with those bids submitted by others determined that we were not competitive. So, it didn’t proceed”.

As previously noted, it was never likely that PILOT *would* be funded. The project was ambitious, and while the science cases were interesting, to win NCRIS funding PILOT had to balance the contradictory framing of selling itself as a pathfinder telescope and presenting itself as a piece of critical, national, strategic infrastructure in its own right. The many reasons it didn’t get funded could include the cost, the political complexities of the Australian relationship with Italy and France in Antarctica, in-fighting within and between the Australian astronomy and Antarctic research community, conflicting priorities, or perhaps most evocatively, the ill-fated tower. Each of those reasons might have been sufficient on its own; remarkably, in PILOT’s case, as we have seen in the previous chapter, a number of determined individuals kept pushing it along against these multiple resistances.

The relevant question from a social studies of science perspective, then, is not so much ‘why PILOT failed’, but rather how it failed. We can give a reasonable accurate answer to the ‘why’ question by outlining the reasons the ANSOC gave for not recommending that it get further funding, which is about as satisfying as conducting an investigation only to declare that a murder victim is dead because they are no longer breathing. The ANSOC report talks about scientific reasons that PILOT didn’t make the cut, but we have seen by now that PILOT did not succeed or fail on scientific reasons alone. There were a range of social, political, structural, and systemic issues that all had a bearing on the result, but which do not show up in the ANSOC report. As Biddington put it, “the documents that I’ve retained don’t give me the flavour”. In order to get a clear picture of *how* PILOT failed to get funded, it is necessary to talk to the people involved who were part of these sociotechnical networks, and could read between the lines of the official story that was framed on grounds of scientific merit alone. Thus, after briefly recapitulating the ‘flavourless’ account of *why* PILOT failed, the purpose of this chapter is to address the larger question of *how* PILOT failed — and thereby to provide an account of the precise alignment of techno-social factors, including the research priorities of Australia’s astronomy community, the state of cooperative efforts at Concordia, and Australia’s

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[188] (2008). Astronomy NCRIS Strategic Options Committee Report to the Board of Astronomy Australia Ltd., Astronomy Australia Ltd. p. 15.

own political understanding of space at the time, as they stood at the moment the ANSOC report was released.

For Biddington, the release of the ANSOC report was the moment that "[PILOT] really died. It was as simple as that". For him, the end was disappointing, but he noted that he was "not surprised. It was always a long shot. I think John [Storey] actually knew that, that it was always a long shot". But when, irresistibly drawn to the murder mystery metaphor, I asked whether any person or thing or organisation *killed* PILOT, Biddington, like everyone else I spoke to, corrected the presumption that for a project to die, there must be a murderer.

> *No. No, no, it … fundamentally, after the review was done and the … you know, we didn't get the money we wanted, there was no point proceeding. You know, there was no funding avenue, John [Storey] was coming to the end of his career at University of New South Wales. The world moved on.*

At first glance, his response to my question fits perfectly with the Aramis narrative: PILOT died because nobody loved it enough. Yet there's something about this conclusion that is unsatisfying. Certainly, there was emotion connected to PILOT. For Storey, in particular, the release of the report was upsetting, and he likened the experience of learning PILOT was not going to be funded to a break-up.

> *It's sort of like when your girlfriend leaves you, if she's leaving you for another bloke that's one thing, but she just leaves you because you're so hopeless she doesn't want to be with anyone, that's really heartbreaking. That's kind of how I felt about PILOT.*

I empathised with Storey. Had I, too, fallen in love with PILOT? Was I, too, persuaded by that photograph of the tower that the whole, ridiculous idea was actually feasible? In the process of documenting its many quirks and flaws, did Latour fall in love with ARAMIS? The truly fascinating thing about PILOT is not that it failed, but how long it took to get to that point. I can't resurrect PILOT, or explain *why* it failed, any better than the ANSOC report does, but what I can do is tell the story of *how* PILOT failed by conceptualising failure as a process comprised of social, technical, political, and structural factors. Then it is possible, as this section will do, to lay out those factors clearly and, in doing so, form an empirical understanding of some significant elements that structured the Australian space sciences sector at the time.

Each of the individuals who held a picture of PILOT in their minds participated in my research for their own reasons, which they may or may not have disclosed. Some told me that they were interested to better understand their own career and its relationship with dual-use technology and ethics. Some participated because of social exchanges and reciprocity — they did an interview as a favour to me. Some were just kind people, happy to help a PhD student. But Storey's case is particularly unique in that, in addition to all these factors, his cooperation and assistance with my research was also partially driven by his own desire to understand what happened. He hoped that my research would answer the question that had been nagging at him for over a decade: PILOT seemed so obvious. So why had no-one built a serious telescope at Dome C since? Was the idea really such a bad one? The others were broadly interested, but Storey was seeking closure. By this point, two years on, and with phantom towers and mysterious debris-cameras still dancing as vividly in my imagination as they had on first hearing about PILOT, so was I.

3.1 Why did PILOT fail to win funding?

One of the frustrations for those involved in the PILOT bid was that at times the ANSOC report was contradictory. On the one hand, the ANSOC wrote with genuine-sounding enthusiasm that Dome C as an exciting possibility for science, “the atmospheric characteristics appear to be outstanding, quite possibly the best in the world for optical-infrared observing”.[189] In the same breath, the report also says how the “environmental conditions for astronomical observations have been found to be very challenging”. After equivocating on the technical and environmental issues, the formal recommendation from ANSOC, that PILOT should not be funded, boils down to their assessment that it was both too big, complex, and expensive, and not big, complex, and expensive enough. The three paradoxes that emerge from a close reading of the decision may be summarised as follows:

1. The scale of the project was too large (both in terms of international management and cost) for a university-led-approach, but too small to be undertaken as a proper international-scale project;
2. There were some technological challenges which had only been theoretically solved (e.g. humidity, the tower), but could not be solved in practice without further funding; and
3. International collaborators had not committed to the construction of PILOT, but they would not commit until Australia did so.

Although the ANSOC must have known that, without their recommendation for funding, further studies were not feasible, they suggested at the conclusion of the report that further studies should be carried out. Beyond the obvious Catch-22 flavour, it’s worth also pointing out that there was a genuine reason that PILOT offered less certainty than the other options, which was that a Phase A study is not a Phase B study. PILOT never got beyond the conceptual design phase, and was being ranked against projects that had. As Lawrence said,

> *… this is common of these types of projects, right. You know, you start with a concept, and maybe it’s a vague concept, at least to start with, and then you do a study, you know, like we did for PILOT, we did a Phase A concept study, conceptual design, and you’re only spending a fraction of the budget at that point. So you don’t, you know, you don’t really, you don’t answer all the questions, you don’t expect to answer all the questions as to actually how everything is going to be built and is it guaranteed to succeed, because you have a full, complete engineered solution. It’s not until you go to fund the next phase that costs more money, you go to Phase B, or preliminary design, we call it, and then, you, again, you spend more money getting more insight into what the solutions are.*

For a risk-averse committee, recommending that money be put towards funding a Phase B study for PILOT, rather than simply buying a stake in other projects that were more certain and had more momentum behind them, was a big ask. Yet in theory, it could have been possible to allocate a small amount to fund the next phase of development without committing AAL to the entire $100+ million project. The following sections dig into some of the reasons that sit within the subtext of the report, and that are not mentioned but nonetheless may have played into the decision not the fund a Phase B study for PILOT.

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[189] Ibid. p. 10.

3.2 How did PILOT fail to win funding? Implicit context for the ANSOC report

The wording of the ANSOC report hints at context for the decision to recommend that PILOT not receive NCRIS funding that was not made explicit in formal documents. In this section, I assemble and juxtapose diverse perspectives of the individuals I interviewed for this research as to the surrounding circumstances that influenced the decision of the Committee. At times their views were at odds with each other, so, as before, rather than present once single narrative I have instead constructed a series of four factors, thematically arranged, which read together provide the most complete picture of how the PILOT proposal was out-of-step with its context. First, I establish that PILOT's main competition was the GMT-DDP proposal, and discuss why it was that the astronomy community at the time favoured the GMT-DDP over PILOT. Second, I unpack the reasons behind the unwillingness of Australia's international partners to commit to funding PILOT, describing the barries to scientific cooperation at Concordia that emerged in the years leading up to the 2008 NCRIS bid, some of which were directly related to Australian activity at Dome C, and some of which were incidental but nonetheless influential. Third, I assess in greater detail how Australia's strategic and diplomatic objectives shaped the perceived need for an Antarctic telescope, demonstrating that PILOT addressed a need that had, at that time, not yet been articulated at a policy level. Finally, I examine Australia's burgeoning space industry at the time that PILOT was proposed, and show how the dual-use element to PILOT's proposed design was both too far behind for Australia's defence-aligned industry, and too far ahead of governmental processes that did not yet have the capacity, at a policy level, to administer such a dual-use project.

3.2.1 PILOT's place in Australian astronomy

As Biddington framed it to me, there were "three tribes" of astronomers in Australia at the time the NCRIS process was occurring who were competing for funds: the radio astronomers, the optical astronomers, and the Antarctic astronomers. Radio astronomy at that time was primarily concerned with the Australian Square Kilometre Array Pathfinder (ASKAP) project, which did not make a pitch for money from the NCRIS Strategic Options Fund. The process therefore pitched various optical and Antarctic astronomy groups against one another. In the round of funding for which PILOT was put forward, it competed with 'Investment in the Giant Magellan Telescope Design and Development Phase (GMT-DDP)' to purchase a 5% Australian national share,[190] and the 'Additional Access to 8-Metre Class Telescopes' bid, which proposed to purchase 15 additional nights per year on the Magellan 6.5-metre telescopes and 12 nights on the Gemini 8-metre telescopes.[191]

In considering the academic needs of Australia's optical-infrared astronomers, the ANSOC report states that "dependable long-term access to 8-m-class telescopes at a level appropriate to the size of the community is essential if Australia is to maintain its competitiveness in international astronomy".[192] It notes that "in light of the recent productivity of Australian astronomers who have used [8-m telescope] facilities, measured by both the number of papers and their citations",[193] ensuring that Australian researchers continued to be able to access these telescopes at a significant level (quantified as 20% of one 8-m telescope) "can be fully justified".[194] From the perspective of ANSOC, who needed to sustain optical astronomy as an industry, the purchase of additional time on overseas telescopes was a quick stop-gap solution that could enable more strategic deployment of funds on a longer-term project over which Australia might have greater influence.

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[190] Ibid. p. 9.
[191] Ibid. p. 7.
[192] Ibid. p. 8.
[193] Ibid. p. 8.
[194] Ibid. p. 8.

GMT-DDP and PILOT were therefore both competing over what money remained after expenditure on the Magellan and Gemini telescopes, and there was only enough money left in the pot to fund one of them. Neither PILOT nor the GMT-DDP could promise papers or citations in high volume in the short-term. Both were projects that required significant investment in the hope of conducting 'competitive research' a decade down the line. Saunders felt that at this point in the process people with influence in Australian astronomy, including Colless, simply wanted GMT-DDP more than PILOT.

> *… powerful people in Australia wanted to be part of that project [GMT-DDP] - Warwick Couch and Matthew Colless, both who, at some stage, were heads and directors of the AAO. They were heavily involved with GMT, so if they're … and, so they're not going to support PILOT. I won't go as far saying that they were, strongly against it, but they certainly didn't support it.*

From a cost-benefit perspective, GMT-DDP had a structural advantage underpinning Colless and Couch's perspective on its value. In 2007 the Australian National University (ANU) had purchased, unilaterally, a 5% share in the GMT-DDP "that gave ANU a seat on the GMT Board and the means of participating in the DDP".[195] The ANSOC proposal stated that purchasing an additional 5% as a national stake would allow Australia to participate at a 10% level,[196] which they framed as "the minimum that would be necessary to influence and impact decisions made on the telescope characteristics and capabilities to match Australian aspirations".[197] Additionally, a higher level of financial participation would improve the visibility of Australia's astronomers at an international level. It was the view of the ANSOC panel that:

> *… participation in an ELT [Extremely Large Telescope] was necessary for any astronomical community whose vision and goal was to remain at the cutting edge of scientific endeavours in the next decade and beyond. As noted above, the planned investment in radio facilities on the scale of SKA will also be leveraged by having a strong Australian optical-infrared community with access to the world's largest telescopes. This will ensure that the scientific discoveries made with observations from joint programs on SKA and ELTs will be carried out, and seen to be carried out, by Australian astronomers.*[198]

But the question remained: which ELT? At the time there were three ELT projects "under conceptual development, the GMT and Thirty Metre Telescope (TMT) in the USA, and the European Extremely Large Telescope (E-ELT) in Europe". [199] The view of the ANSOC panel was that whichever project Australia participated in, "to be a significant player, comparable to other members, Australia should have a minimum 10% share".[200] The fact that ANU had already moved to purchase a 5% stake in the GMT-DDP could be seen to have, in some ways, forced ANSOC's hand in their decision to fund the additional 5% out of the NCRIS funds in 2008. From this perspective, PILOT never had a chance of securing funding, because it was not seen to offer 'quick wins' in the form of publications or citations. Compared to GMT-DDP, PILOT made less logical sense than doubling down on a stake in a project on which an Australian institution already held a board seat.

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[195] Ibid. p. 9.
[196] Ibid. p. 9.
[197] Ibid. p. 9.
[198] Ibid. p. 9.
[199] Ibid. p. 9.
[200] Ibid. p. 10.

3.2.2 PILOT's place in international scientific cooperation

Sitting behind the perceived lack of commitment from international collaborators was a very real disintegration of the cooperative relationship between the Australian research team and their Italian and French partners with tangible repercussions. Members of the PILOT team had been spending summers at Concordia, supported by the French and Italian programs, for several years. But at the time of the NCRIS proposal, support for an Australian presence at Dome C, which Travouillon confirmed was essential, was no longer available.

> *I think the logistics required was a bit too much of the time, and so getting the support from the European Antarctic agencies, like the IPEV [Polar Institute Paul-Emile Victor] and PNRA [Programma Nazionale di Ricerche in Antartide] was just not there yet. Even though the scientists were there, I think the logistics was not quite up to par for this, and so … Without the full support, without everybody signing up for it, it made things harder, that's for sure.*[201]

Logistics support is extremely expensive in Antarctica, and there is an opportunity cost as well as a financial cost that comes with dedicating any resources to supporting a project, instrument, or life on the continent at any time. As Storey put it, "someone once said that it costs about the same to keep someone at the South Pole as it does to keep them in intensive care". In the scientific-political currency of Antarctica, symbolic visibility is therefore more important than it is elsewhere, because logistics are exchanged, rather than services being purchased. It was for that reason that Storey, Lawrence and Travouillon decided to add the American flag to the display of the Italian, French and Australian flags beside the AASTINO (see Figure 6): crudely put, flying the American flag was a way of 'paying' for the Iridium satellite logistics support that the US Antarctic Program was providing to the project.

It was partially the symbolically loaded meaning of these flags that contributed to PILOT's problems in terms of securing support from international colleagues. After the 2002-2003 season, when Storey, Lawrence and Travouillon constructed the AASTINO at Dome C, they left a camera set up to take a photograph every day out the window of the AASTINO — and an Australian flag flying in view of the camera. Storey explained that the 100 photographs the camera took from the time they left showed that the site was excellent for astronomy in a way that complemented the data.

> *… after we left at the end of February, this thing worked for 100 days, and we had 100 days of images of what the sky looked like at Concordia. It was just brilliant. Not a cloud, I think there was maybe two cloudy days and the whole hundred days, it was just stunning. It showed that this site was really something else. And best of all this Australian flag, which is mostly just hanging limply, saying there's just no wind here. This is the place to build an observatory. And we were really, really excited.*

The team went on to make a poster 10-15 metres long, featuring every one of the 100 photographs, which they took to international conferences. It was then, according to Storey, that "a couple of things went seriously wrong".

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[201] The IPEV is the French agency responsible for Antarctic activities. IPEV stands for Polar Institute Paul-Émile Victor. The PNRA is the Italian agency responsible for Antarctic activities. PNRA stands for Programma Nazionale di Ricerche in Antartide.

Figure 15 — One of the first photographs taken from the AASTINO, showing the (infamous) Australian flag.[202]

The following year, for the 2003-04 Antarctic season, Storey returned to Concordia with then-PhD student Anna Moore.[203] Although Storey recalls that Zucchelli, who by then was suffering from tongue cancer, remained enthusiastic about the presence of the Australians, the French and Italian astronomers at Concordia were less positive, and declined the Australians' offers to use the AASTINO to power their experiments and provide communications over the winter. In Storey's retelling, it was the poster showing the photographs of the Australian flags that had caused the tension, because of the symbolic exclusion of French and Italian support these images presented.

> *Partly, people were pissed off that we had produced all these posters and pictures of the Australian flag there. And they thought, this should be a French and Italian flag. I can kind of see their point but, it even got to the point where the French astronomers were showing our images of the blue sky and so on, with the Australian flag cropped out of the image. So it did get a little bit silly.*

A further moment of focus for simmering tensions between the French team at Dome C and the Australian researchers came with the publication of a paper in *Nature* that described the quality of the seeing conditions at Dome C and claimed that the location rivalled space.[204] This paper was based on the data collected from the instruments powered by the AASTINO. It is the list of authors,

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[202] Photograph provided by John Storey as additional material to supplement our research interviews: Storey, J. (2020). Research Interview 1 of 2. HREC 2020/145. A. Handmer.; Storey, J. (2020). Research Interview 2 of 2. HREC 2020/145. A. Handmer.

[203] Like Travouillon, Moore also ended up at ANU, where she currently holds the positions of Director of the ANU Institute for Space (InSpace) and Director of the Advanced Instrumentation and Technology Centre (AITC) at Mount Stromlo Observatory. See (2020). "Director." Biography Retrieved 11/09/2021, from https://inspace.anu.edu.au/about/anna-moore.

[204] Lawrence, J. S., M. C. B. Ashley, A. Tokovinin and T. Travouillon (2004). "Exceptional Astronomical Seeing Conditions Above Dome C in Antarctica." Nature **431**: 278–281.

rather than the content of this paper, that was the cause of the breach with the French contributors. Only four names are listed: Jon Lawrence, Michael Ashley, and Tony Travouillon (all from UNSW's School of Physics), and Andrei Tokovinin, from Cerro-Tololo Inter American Observatory, Chile. None of the names of any of the Italian or French collaborators at Dome C were included as authors on what was the definitive paper on the project. While the *Nature* paper did thank the French and Italian Antarctic research programs in the *Acknowledgements* section, the paper does not mention any international individuals or institutions by name, at the same time thanking a number of UNSW collaborators, including Storey, individually.[205] Storey acknowledges that this was a "really bad political judgement", and that the omission of French authors on the paper "pretty well was the end of French-Australian cooperation at Dome C". But he was keen to explain that it was a decision made on principle.

> *I was a little bit pissed off, I think at that point, about the number of people that end up on publications who had absolutely nothing to do with the publication, but just sort of feel that they should be on it by right. And although I'd basically put this project together, and done all the negotiations, and built the thing down in, or helped install it down at Dome C, I just thought I wouldn't put my name on the paper; that I would just have the absolute key people, which was the post-doc Jon Lawrence, the PhD student Tony Travouillon, the Russian guy Andrei Tokovinin, and I think Michael Ashley who'd done all the computer back-end stuff. So, they were the key people.*

Nonetheless, Storey remains confused as to why the flag images and the paper publication seem to have caused such an irreparable schism so quickly: his application to take a small team down to Concordia for the 2004-2005 summer, to try to replicate the data written up in the *Nature* paper, was denied.

> *… we were told no. There's no room for you. We can't find space for the people … And we're going to go down and do our own measurements in the summertime, but we don't … we can't support you guys in the summer.*

It seems likely, from piecing together other narrative threads, that the impact of the paper and the poster was compounded significantly by the death in late 2004 of a (arguably the) key supporter of the Australian astronomers' presence at Dome C: station leader Mario Zucchelli. Guillaume Dargaud, who spent many seasons at Dome C and elsewhere in Antarctica, and who wrote extensively about his experiences in his online blog, noted at the time the change in atmosphere in the absence of Zucchelli.[206]

> *… many of the people haven't changed much, with the notable exception of Mario Zucchelli, the efficient and feared head of the Italian Polar Project who died recently. It probably explains why there are now some people enjoying the scenery instead of running around carrying stuff and acting busy.*

Storey's recollections align with Dargaurd's description, although Storey takes the next logical step in drawing a link between Zucchelli's death and lessened tolerance for his own presence at Concordia.

> *It turns out that he was, apparently, quite an autocratic leader, and was not universally liked within the Italian program, and I think more particularly within the French program. And so I*

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[205] Ibid. p. 281.

[206] Dargaud, G. (2005). "The First Winter-Over at Concordia." Guillaume & Jennifer Dargaud's website https://www.gdargaud.net/Antarctica/WinterDC1.html.

> *think a lot of what he had wanted to do was … People saw their opportunity to not build this legacy further. And we suddenly found ourselves no longer terribly welcome at Dome C.*

Lawrence clarified that despite “some politics in the background”, or an awareness on his part that “the French were not entirely happy about us being there, or were not entirely supportive of what we were doing”, the researchers at Dome C were always polite and welcoming in person, and that they remained on speaking terms. However, his perspective aligned with Storey’s in that he saw their publication of site testing results in particular as having trodden on some toes.

> *… you know, there’s a French group who were doing site testing, and they’ve been going there for summer [after] summer [after] summer, and they haven’t really published anything, and then we, ah, we just sort of came in and published …*

Lawrence also wondered whether, in the absence of Zucchelli’s leadership, the teams remaining at Dome C lacked “a concrete vision of what Dome C was about”.

> *You know, they did all the ice coring stuff, and that was clearly a big, important thing, you know, they drilled down to, you know, 3km, or whatever. And that took a lot of resources and energy and everything over, I think, the early 2000s, and then it wasn’t clear that they had a vision, like ‘Dome C should do this one thing’, and perhaps there was some tension there, as to, you know, what they thought? Why should they listen to these Australians coming in and telling them to build a big telescope? Some people were behind that, I’m sure others had other ideas, so maybe that had something to do with it?*

When I asked Colless about it, he agreed that Zucchelli’s death seemed to have affected the broader cooperative spirit at Concordia between France and Italy, and that beyond the issue of the flags or the publication of results, “the French and the Italians had a falling out, and a big fight, about how they were running their base there. And so the base didn’t look like such a good idea”. Nonetheless, it seemed for a time that whether or not the Australians were *personae non gratae*, a French-Italian cooperative astronomy project at Dome C may have still succeeded, backed by funding for cooperative European research. In October 2006 the first (of three) ‘ARENA Conference on Large Astronomical Infrastructures at Concordia: Prospects and Constraints for Antarctic Optical/IR Astronomy’ was held in Roscoff, France.[207] The funding for these conferences had been granted to the University of Nice team by the European Union and their purpose was to discuss possibilities for projects just like PILOT. In the opening address, the conference convenor, Epchtein, from the University of Nice, said that ARENA was about building international consensus and support around a project for Dome C:

> *We are not supposed to consider nor support small experiments, but rather to arouse a consensual interest for one or two world-class projects and to define their road map of development during the coming decade from the point of view of their scientific impact, of the technical challenge that they will implicate and of the supplementary logistics effort that they will require.*[208]

The tone of Epchtein’s opening address was collaborative and conciliatory, acknowledging that “coordination and sharing of expertise is a prerequisite to undertake feasibility, and later on, design

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[207] ARENA stands for Antarctic Research, European Network for Astrophysics. (2006). 1st ARENA Conference on "Large Astronomical Infrastructures at CONCORDIA, prospects and constraints for Antarctic Optical/IR Astronomy", Roscoff, France, EAS.

[208] Epchtein, N. (2006). ARENA: Toward a European Astronomical Facility at Dome C Concordia. 1st ARENA Conference on Astronomy at CONCORDIA, Roscoff, France, EAS. p. 2.

studies of large projects, there, rather than to work independently on individual projects”.[209] Among the topics highlighted by Epchtein as being of importance was the still unsolved question of “how to install a telescope and stabilise it atop a tower”.[210] Australians were well represented at the conference: Storey, Ashley, Burton and Lawrence gave a presentation on PILOT as part of proceedings,[211] and Saunders presented a plan for a ‘Large Reflective Schmidt Telescope’ called ‘WHAT’ (Wide-field Antarctic Horizontal Telescope).[212]

But, according to Storey, the Australians did not receive a warm reception from everyone, particularly Gérard Jugie, Director of the French IPEV, who gave a speech about his vision for Concordia.

> *… he talked about how this was a fantastic observing site for astronomy, and astronomy was going to be a key thing. But that whenever we have international people there in the future, it will be important that they pay for their share of the operating costs. He’d gone into a big spiel about what it costs to run Concordia. And he then went on to say, “and will never again have parasites at the observatory. At the station.” And … everyone in the room looked at me, and I kind of didn’t really know what to say or do. I … if I were generous I’d put it down to language problem, that maybe … Gérard Jugie, I think it was, didn’t quite know what that word really meant in English. But it was, you know, it was almost a declaration of war. That we just don’t want to have this kind of relationship again. And so we never really recovered from that.*

Lawrence explained that eventually the Australians stopped going to Dome C, and shifted focus to other projects. But the idea of a telescope on the Antarctic plateau continued, and in 2010 the team from the University of Nice led by Epchtein tried to get a telescope that Storey described as “PILOT but with a French flag flying over it” funded under the name ‘Polar Large Telescope’ or ‘PLT’.[213] PLT was closely linked to PILOT: the webpage for the Polar Large Telescope states clearly that the Phase B study, planned for 2012-2014 would be undertaken “on the basis of the PILOT phase A study made in Australia (AAO+ UNSW) in 2007-2008”,[214] and that the PLT “is a descoped version of PILOT, a project formerly proposed and studied in phase A by an Australian consortium (UNSW/AAO)”.[215] And, at least initially, the UNSW and AAO teams were involved conceptually and financially in PLT plans. Storey, Ashley, and Lawrence are all named as authors alongside Epchtein and others on a

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[209] Ibid. p. 2.

[210] Hammerschlag, R. H., F. C. M. Bettonvil, A. P. L. Jägers and G. Nielsen (2006). Towers for Antarctic Telescopes, 1st ARENA Conference on Astronomy at CONCORDIA, Roscoff, France, EAS. As referenced in Epchtein, N. (2006). ARENA: Toward a European Astronomical Facility at Dome C Concordia. 1st ARENA Conference on Astronomy at CONCORDIA, Roscoff, France, EAS. p. 2.

[211] Storey, J. W. V., M. C. B. Ashley, M. G. Burton and J. S. Lawrence (2006). PILOT — the Pathfinder for an International Large Optical Telescope, 1st ARENA Conference on Astronomy at CONCORDIA, Roscoff, France, EAS.

[212] Saunders, W. and A. J. McGrath (2006). WHAT? A Large Reflective Schmidt Telescope for the Antarctic Plateau. 1st ARENA Conference on Astronomy at CONCORDIA, Roscoff, France, EAS.

[213] Epchtein, N. (2010, 2012). "Baseline for a Polar Large Telescope." The Polar Large Telescope Retrieved 11/5/21, from https://sites.google.com/site/antarcticlargetelescope/the-polar-large-telescope/main-characteristics-of-the-plt.

[214] Epchtein, N. (2010). "The Polar Large Telescope." The Polar Large Telescope Retrieved 11/5/21, from https://sites.google.com/site/antarcticlargetelescope/the-polar-large-telescope.

[215] Epchtein, N. (2010, 2012). "Baseline for a Polar Large Telescope." The Polar Large Telescope Retrieved 11/5/21, from https://sites.google.com/site/antarcticlargetelescope/the-polar-large-telescope/main-characteristics-of-the-plt.

poster presentation given in May 2011 at the Colloque R&D conference held in Grenoble.[216] PLT as presented ("PILOT, but optical specs. relaxed")[217] has two notable variations from the original PILOT plans: first, in all the available publications about PLT, no mention of space debris is made, and second, while SAGEM makes an appearance as part of the 'PLT Consortium', EOS is absent from the industrial partners mentioned in connection to the project.[218]

When we discussed PILOT, Colless drew a direct link between PILOT and another successive proposal for a telescope called KDUST. He described how, as PILOT faded from Australian plans and PLT lay fallow, the PILOT team spoke to their Chinese counterparts about jointly funding the construction of PILOT at Dome A. The collaboration never came to pass, partly because, according to Colless, "we couldn't come up with a way of both funding it, which would actually make it work". However, China picked up the mantle with their proposals for a telescope called Kunlun Dark Universe Survey Telescope, 'KDUST', to be built at Dome A. In January 2008 members of the Prydz Bay—Amery Ice Shelf—Zhongshan—Dome A (PANDA) program led by the Polar Research Institute of China (PRIC) and the Chinese Centre for Antarctica Astronomy (CCAA) deployed an updated version of the AASTINO called PLATO (PLATeau Observatory), built by UNSW, to Dome A.[219] The site testing that the PLATO enabled fed into a series of papers, beginning in 2010,[220] and culminating in a presentation of the preliminary design at the proceedings of the International Astronomical Union Symposium in 2012.[221] Colless told me that "you could read large chunks of text from the PILOT study in the KDUST study". Like PILOT, KDUST would be a 2.5m optical / infrared facility, perched atop a tower.[222] At one point in 2011 the suggestion was even made that PILOT, PLT and KDUST could merge, "and set up appropriate science team and management structure".[223]

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[216] Epchtein, N., W. Ansorge, L. Abe, M. Langlois, I. Vauglin, B. L. Roux, M. Carbillet, S. Argentini, C. Genthon, R. Lemrani, T. L. Bertre, G. Marchiori, J. Montnacher, C. David, I. Esau, E. Ruch, I. Bryson, G. Dalton, M. Ashley, J. Storey, J. Lawrence and consortium (2011). The Polar Large Telescope: an Infrared Large Synoptic Survey Telescope. Colloque R&D, École thématique du CNRS, Grenoble, France, Recherche et Developpement pour l'Astronomie et l'Astrophysique.

[217] Epchtein, N., W. Ansorge, L. Abe, M. Langlois, I. Vauglin, B. L. Roux, M. Carbillet, S. Argentini, C. Genthon, R. Lemrani, T. L. Bertre, G. Marchiori, J. Montnacher, C. David, I. Esau, E. Ruch, I. Bryson, G. Dalton, M. Ashley, J. Storey, J. Lawrence and Consortium (2011). The Polar Large Telescope (PLT): a Synoptic Survey of the Southern Sky in the infrared Workshop Astro-Antarctica, Marseille. slide. 3.

[218] Ibid. see also Epchtein, N., W. Ansorge, L. Abe, M. Langlois, I. Vauglin, B. L. Roux, M. Carbillet, S. Argentini, C. Genthon, R. Lemrani, T. L. Bertre, G. Marchiori, J. Montnacher, C. David, I. Esau, E. Ruch, I. Bryson, G. Dalton, M. Ashley, J. Storey, J. Lawrence and consortium (2011). The Polar Large Telescope: an Infrared Large Synoptic Survey Telescope. Colloque R&D, École thématique du CNRS, Grenoble, France, Recherche et Developpement pour l'Astronomie et l'Astrophysique. slide. 16.

[219] Storey, J. W. V., M. C. B. Ashley, Y. Augarten, C. S. Bonner, M. G. Burton, L. Bycroft, J. R. Everett, J. S. Lawrence, D. Luong-Van, S. McDaid, C. McLaren and G. Summers (2012). The PLATO Robotic Antarctic Observatory Design and Development Program. Second Workshop on Robotic Autonomous Observatories, ASI Conference Series. p. 99. and Zhao, G.-B., H. Zhan, L. Wang, Z. Fan and X. Zhang (2011). "Probing Dark Energy with the Kunlun Dark Universe Survey Telescope." Publications of the Astronomical Society of the Pacific **123**: 725-734. p. 725.

[220] Zhao, G.-B., H. Zhan, L. Wang, Z. Fan and X. Zhang (2011). "Probing Dark Energy with the Kunlun Dark Universe Survey Telescope." Publications of the Astronomical Society of the Pacific **123**: 725-734. p. 725.

[221] Yuan, X., X. Cui, D.-Q. Su, Y. Zhu, L. Wang, B. Gu, X. Gong and X. Li (2012). Preliminary Design of the Kunlun Dark Universe Survey Telescope (KDUST). Astrophysics from Antarctica, IAU Symposium No. 288, International Astronomical Union.

[222] Ibid. p. 272.

[223] Epchtein, N., W. Ansorge, L. Abe, M. Langlois, I. Vauglin, B. L. Roux, M. Carbillet, S. Argentini, C. Genthon, R. Lemrani, T. L. Bertre, G. Marchiori, J. Montnacher, C. David, I. Esau, E. Ruch, I. Bryson, G. Dalton, M. Ashley, J. Storey, J. Lawrence and Consortium (2011). The Polar Large Telescope (PLT): a Synoptic Survey of the Southern Sky in the infrared Workshop Astro-Antarctica, Marseille. slide. 19.

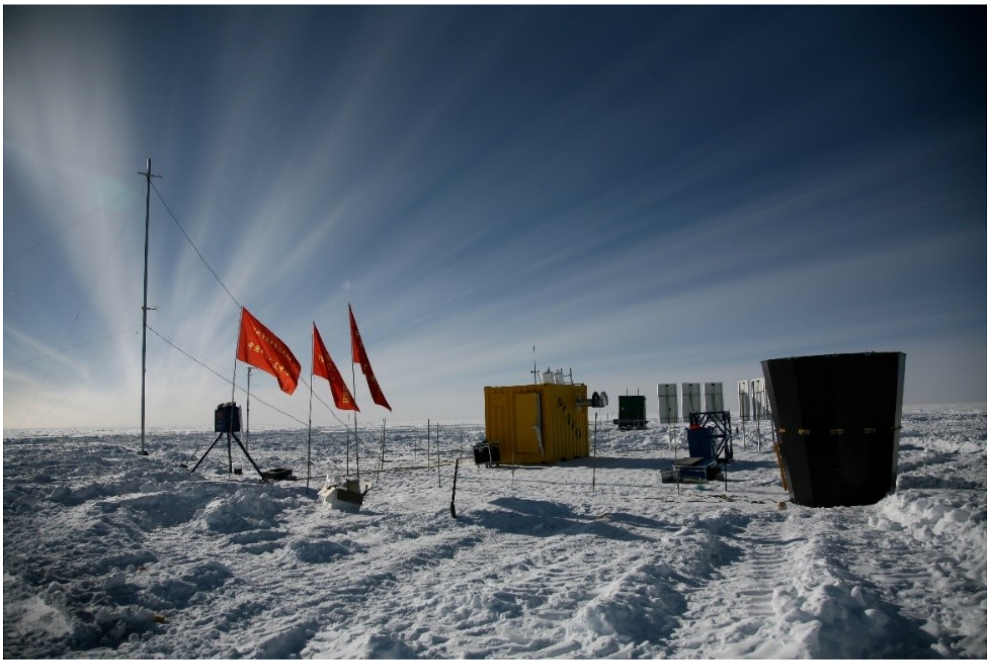

Figure 16 —PLATO in position at Dome A.[224]

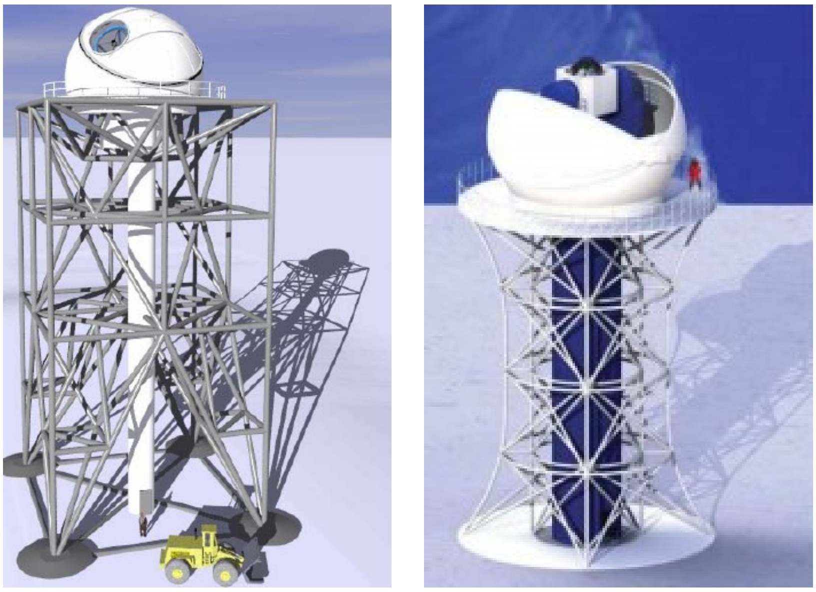

*Figure 17 — **Left**: A design rendering for PILOT atop a 30-metre tower, as it appeared in a proposal presentation for PLT in 2011. **Right**: A design rendering of KDUST on a 15-metre tower, from the Design Study presented in 2012.*[225]

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[224] Photograph, originally provided to Storey by the Chinese Antarctic astronomy team. Storey passed this photograph on to me as additional material to supplement our research interviews: Storey, J. (2020). Research Interview 1 of 2. HREC 2020/145. A. Handmer.; Storey, J. (2020). Research Interview 2 of 2. HREC 2020/145. A. Handmer.

[225] Epchtein, N., W. Ansorge, L. Abe, M. Langlois, I. Vauglin, B. L. Roux, M. Carbillet, S. Argentini, C. Genthon, R. Lemrani, T. L. Bertre, G. Marchiori, J. Montnacher, C. David, I. Esau, E. Ruch, I. Bryson, G. Dalton, M. Ashley, J. Storey, J. Lawrence and Consortium (2011). The Polar Large Telescope (PLT): a Synoptic Survey of the Southern Sky in the infrared Workshop Astro-Antarctica, Marseille. slide. 6.; Yuan, X., X. Cui, D.-Q. Su, Y. Zhu, L. Wang, B. Gu, X. Gong and X. Li (2012). Preliminary Design of the Kunlun Dark Universe Survey Telescope (KDUST). Astrophysics from Antarctica, IAU Symposium No. 288, International Astronomical Union. p. 273.

But like PILOT, and PLT, KDUST has not yet actually been built. In a process eerily evocative of NCRIS, KDUST was submitted to the Chinese government for review as of July 2018, one of two major facilities planned for the Kunlun Observatory at Dome A, and “listed as National Large Research Infrastructure during [the] 12th Five-year plan”.[226] Travouillon and Lawrence remain part of KDUST’s ongoing story, visiting the Nanjing Institute of Astronomical Optics and Technology (NIAOT) to discuss plans in May 2019.[227] Whether KDUST will succeed where PILOT failed is not yet clear, and of course the specific social, structural, economic, and political context for KDUST is different from that that existed in Australia in the mid-late 2000s, but echoes of PILOT are strong in the design, science cases, funding struggles, and governance discussions.

I wonder whether Storey would have felt more positively about PILOT’s ‘failure’ if the relationship with his international colleagues had not soured. What is clear is that for Storey, the priority was always the telescope, and he would have seen PILOT as a success if it had been built at all, regardless of who built it or which flag flew over it. But what Storey perhaps neglected at the time was how deeply important these symbolic gestures (flags, author credits, acknowledgements) were within the political structures that underpinned logistics exchanges which were the currency of Antarctic activity. Thus, as Travouillon noted, the lack of logistics support from the team at Concordia (“cranes and trucks that have a specific load”), not any single technological hurdle, was “probably the single largest contributor” to PILOT not being built.

The international cooperation component of PILOT was more important than it initially appeared. Beyond the interpersonal challenges, there were networks of relations which operated on exchanges of symbols and meaning, and the exchange continued to occur whether or not Storey chose to pay attention to it. Without the backing of Mario Zucchelli, Storey found himself in a situation where neglect of these networks of reciprocity (e.g. we make your PhD student snails for his birthday, you keep quiet about the imaginary cat we invented to fool you; you invite us to collect data at your site, we name you on our paper) had alienated many of the individuals and institutions who he needed to lobby in favour for the project.[228] They may not have actively fought *against* PILOT, but they were not prepared to go out of their way to fight for it.

3.2.3 PILOT place in Australia’s national strategy

Where Storey mourned his telescope, Biddington’s disappointment arose from a sense of ‘lost opportunity’. Biddington saw the rejection of PILOT as another symptom of what he called Australia’s “profoundly, long-running, anti-intellectual tradition”. As a project, PILOT was undeniably risky. It was expensive, it was complicated, it was logistically difficult. But as Lawrence pointed out to me, PILOT would not have been the first ambitious project to be attempted in Antarctica. IceCube, for example, is a neutrino observatory at the South Pole whose construction took seven years.[229] The process involved melting kilometres-deep holes in the ice, down which 86 cables, holding a total of

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[226] Li, Z., X. Yuan, X. Cui, L. Wang, Z. Shang, F. Du, X. Gong, B. Gu, Y. Hu, P. Jiang, X. Li, H. Lu, B. Ma, F. Wei, H. Wen, J. Xu, S. Yang and H. Zhou (2018). Introduction of Chinese Antarctic Optical Telescopes, SPIE. p. 6.

[227] (2019). "Australian AAO Delegation Visited NIAOT."   Retrieved 12/05/2021, from http://english.niaot.cas.cn/ns/201906/t20190619_211879.html.

[228] The notions of gift and gift exchange, going back to Marcel Mauss’s 1924 ‘Essai sur le don’, have long informed scholarship in the sociology of science as a way of understanding community creation. In the context of modern science, see e.g. Creager, A. N. H. (2013). Life Atomic: A History of Radioisotopes in Science and Medicine, University of Chicago Press. and Anderson, W. (2000). "The Possession of Kuru: Medical Science and Biocolonial Exchange." Comparative Studies in Society and History **42**(4): 713-744. for an overview of the analytic uses of the concept.

[229] (2021). "IceCube Quick Facts." IceCube South Pole Neutrino Observatory Retrieved 12 May 2021, from https://icecube.wisc.edu/about-us/facts/.

5,160 detector modules, were deployed to form a cubic kilometre array.[230] South Pole Telescope (SPT) is a 10-metre microwave, millimetre and sub-millimetre telescope which was deployed to the Amundsen-Scott Station in the summer of 2006-2007, a process that involved shipping components from Texas to New Zealand and then flying them to the pole.[231] As Lawrence pointed out to me, "telescopes are always in remote environments and challenging, high altitudes and all the rest of it". Since PILOT was "similarly as challenging" as other projects that have been successful in Antarctica, to Lawrence, "there's no reasons why it couldn't have succeeded".

The issue Lawrence points to is that the panel chose "the safe route". It was a lower risk option to approve purchasing time on a telescope that was not Australia's responsibility than it was to be innovators and leaders internationally on a project. He acknowledges that it's hard to take on the innovator role when "the facilities are bigger and bigger and more expensive and just require vast amounts of money", and that most astronomy projects require a "long, slow process", but nonetheless feels that Australia could be more ambitious.

> *They saw that other option as being … safe. And you know, to be honest, I think that's probably the fundamental reason, is that the panel chose the, the kind of, the safe route. Let's put our money in … someone else has built this telescope, let's just give them some money, and they'll give us some time, and that's … sure, that's risk free, we know we're going to get a return, we know that we're going to get to write some papers, and, fundamentally the decision is, do you want to do that, or would you rather take some risks and be more of a … play more of a leading role in a, you know, in an innovative, new project that may lead to new things? Or do you want to just do what everyone else is doing.*

Biddington's perspective also suggests that, in addition to nervousness on the technical side, the international nature of PILOT might have dissuaded a committee from pursuing it. In his view,

> *… we're not critical enough, or strong enough, in our own understanding of our place in the world to make investments that are for our interests, fundamentally, and more importantly than in the interests of others.*

To Biddington, PILOT as a telescope project was less about the science, and more about the extent to which Australia was willing and able to step onto the international stage. The story of PILOT's 'failure' was likewise more about domestic politics and the character of Australia's national strategic policy at the time than it was about the technical challenges. He felt strongly that PILOT would have brought "legitimacy" to Australia's Antarctic claim to 42% of the continent,[232] as well as being a timely investment in Australia's future security interests.

Specifically, Biddington saw PILOT as an opportunity for Australia to reassert itself on the Antarctic continent within the framework of the Antarctic Treaty System. As he explained:

> *… the strength of the Antarctic Treaty, somewhat ironically in my view, has somewhat been related to the extent to which the claimant states have demonstrated a willingness to invest*

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[230] Ibid.
For more about IceCube, see Bowen, M. (2017). The Telescope in the Ice: Inventing a new astronomy at the South Pole. New York, St. Martins Press.

[231] (2012). "Science Goals: Celebrating a Century of Science and Exploration." U.S. South Pole Station: Supporting Science Retrieved 12 May 2021, from https://www.nsf.gov/news/special_reports/livingsouthpole/sciencegoals.jsp.

[232] (2016, 15/04/2016). "Australian Antarctic Territory." Australian Antarctic Program Retrieved 25/09/2021, from https://www.antarctica.gov.au/about-antarctica/australia-in-antarctica/australian-antarctic-territory/.

> *in their claims. Even though the claims are not recognised by the US, China, and Russia especially, the fact that you're investing in your claim makes it harder for people to simply walk all over you.*

Not only might PILOT have offered a visible symbol of Australian involvement in Antarctic affairs, but it would also have provided optionality in future as a piece of dual-use security infrastructure.

> *… if we'd then overlayed on that the national security piece, which in the late, you know, the first decade of the 2000s, was really just coming to, to the front, we'd have been exceptionally well-placed then to say 'well, guess what. This instrument can do something else'. Like space debris measurement, monitoring, or satellite tracking, or whatever.*

The national governmental body responsible for managing Australia's interests and activities in Antarctica under the Antarctic Treaty System is the Australian Antarctic Division (AAD). The AAD was part of JACARA and was institutionally represented on JACARA's Steering Committee,[233] but despite enthusiasm from individuals working with the AAD, the department's research interests at the time did not include astronomy. Beyond providing some small grants to support JACARA's efforts, Lawrence recalls that attempts from the PILOT team to "get a bit more interest and potentially funding from the AAD" "didn't get anywhere". Lawrence felt that the Antarctic astronomers "perhaps weren't seen as a large enough community or perhaps it was seen as a divergence from the main focus of the AAD, and you know, maybe that's reasonable". Lawrence explained that the AAD had a historic alignment between landscape and scientific expertise which was focused on the coast, not on the plateau areas more suited to astronomy.

Biddington provided additional context for how the AAD had been shaped by Australia's geopolitical interests as well as its historic scientific activities. He explained that the focus of government policy at the time was "really about the oceans surrounding East Antarctica, and the protections of the oceans and the biomass". As scientific programs were brought into alignment with political priorities, Australia "lost the capability to move from our stations on the coast inland more than about 30 miles — essentially skidoo range", because the AAD no longer had traverse capability. So without "the traverse capability of tractors and sleds and so on that we'd had in the past", and without Antarctic aircraft, the AAD was not structurally set up to support inland astronomy. It may well have been the case that Australia could have become leaders in Antarctic astronomy, and even that the AAD could have invested in developing this capability, and perhaps thrown their institutional weight, political support, and even funding behind PILOT. For the AAD, the scientific opportunity presented by such a project was not sufficiently appetising to outweigh a decade (and more) of social and structural factors that would have required significant investment and political momentum to overcome.

Thus, while the ANSOC committee, many members of whom were based overseas, may have genuinely expected that PILOT would go ahead, funded through some other national science channel, what Biddington points to here is a culturally-specific policy gap in Australia at the time. NCRIS was a process that aimed to fund strategic national research infrastructure, but there was no unified national strategy that bridged the particular elements that combined within the PILOT proposal: science, security, space, international cooperation, and leadership in Antarctica. Without a national identity that aligned with multilateral leadership, the instinct of those who could have picked PILOT up as a project outside of NCRIS may have been to sit back and let others move first

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[233] (n.d., 05/12/2008). "About Us." JACARA: The Joint Australian Centre for Astrophysical Research in Antarctica Retrieved 25/09/2021.

(or, as Biddington phrased it, “we make highfalutin statements and don’t back them up with money”). Even if such a policy, underpinned by a unified sense of national identity, had existed, PILOT was not recognisably Australian in a way that would have advanced, through symbolic means, Australia’s interests. It was, by design, an international facility. The AASTINO was painted green and gold, but the Australian flag no longer flew over it. The telescope was not located in Australia, but far away in an area of Antarctica that might be called the ‘Australian Antarctic Territory’ but over which Australia had no current, actionable territorial claim under the specific international law that governs the continent. The actual location was not at an Australian station, but at a French-Italian base. The name of the telescope, PILOT, was an acronym that had no obvious link to Australian history or culture. It is pure conjecture, but maybe if PILOT had kept the name ‘Douglas Mawson Telescope’ which spoke to Australia’s history of leadership and risk-taking in Antarctica, it would have been more politically attractive to an Australian Government. What Biddington raises here is that shifting political priorities have a direct link to which scientific programs are funded, and that PILOT did not align with the particular priorities of the time, either practically or symbolically.

3.2.4 PILOT’s place in the emerging space industry

> *… and then John [Storey] got this money for, for a PILOT study, and the AAO came up with this, with this design and costed it … and costed it, quite … well it seemed conservative to me and it came up with a cost of, I think it was $128 million. Something like that, for the whole project. And people suddenly went, woah! this is real money.*
>
> **Will Saunders, PILOT**

Simple as it sounds, a major issue for PILOT was that it was expensive. EOS may have offered a “very good deal” on the telescope itself, but the cost of the “whole project”, which included transporting the equipment to Antarctica and installing it at Dome C, was prohibitively high, especially without free logistic support from the international teams at Concordia. The NCRIS process, just one more source of money in an already complex web of funding sources, with yet another unique set of criteria to satisfy, was new, and was not fully understood. While NCRIS was, in theory, one of the few ways of securing funding for a major project, it was not, in Lawrence’s view, able to deal with something as expensive and complex as PILOT. Lawrence explained that even today “it’s never quite clear, and there’s never quite one thing, one process” for pitching an astronomy project.

> *… we struggle with that now. The sorts of facilities that we’re trying to build are just much more expensive than the current system is set up to fund. And that was certainly the case back then as well. Like, the Australian Research Council has this series of grants that they roll out every year, and you can apply to them, but you can only get, you know, a few million from that. If you want something which is going to cost tens to hundreds of millions of dollars, there’s just no … you know, outside of NCRIS, and even NCRIS is not really, was never really geared up for that sort of thing. It was all a bit ad hoc, and there’d be an announcement, and then five years later there’d be another opportunity, so it was all just, you know, it’s not well organised or not well … there are no real processes beyond … around getting funding for such facilities in Australia, which I think is a bit of a problem.*

The process for getting PILOT funded had begun “from whenever we conceived it in the early 2000s”, slowly socialising the idea with the astronomy community in Australia and building consensus gradually. The individuals behind PILOT were, at this time, well-schooled in how this should be done to best navigate the disparate funding sources. Thus, as AAO Director, Colless had made available the initial pot of what he called “reptile funds money; you know, the money you find under stones somewhere” to support the development of a proposal that could then competitively secure “grant money”. Storey understood the importance of having PILOT appear prominently in the Decadal Plan. The NCRIS process, designed to streamline this intricate dance which Storey had spent a career learning, bypassed the careful networking and consensus-building process, and replaced it with a single panel of experts who, faced with a finite amount of money, were asked to rank the projects by priority and did so. As Colless put it,

> *… there were lots of other good things, many of which I was also involved in, and it just didn’t get to the top of the queue. Everyone could see it was a good idea, but it didn’t quite get to the top of the queue.*

It’s possible that all the talk about PILOT being actually built spooked those responsible for allocating funding. While PILOT was just an interesting idea, AAL had been happy to provide a small amount of funding for a Phase A study, and may have also been comfortable moving to Phase B. But with the Decadal Plan and NCRIS talking about PILOT as a real piece of infrastructure which would do real science, the costs also became ‘real’. Committing to PILOT-the-telescope, rather than PILOT-the-idea, had an opportunity cost. If NCRIS was the only source of funding that was big enough for a project like PILOT, PILOT would crowd out other potential big projects. Thus, the creation of a unified, dedicated ‘pot’ of money from which priorities were to be funded may have prompted a reaction based on perceived scarcity and finiteness of resources that may not have been triggered if PILOT had instead been funded from several different and unconnected sources.

What NCRIS also did was require a mainly scientifically trained team to try to justify PILOT as a piece of national research infrastructure. In the process of trying to expand PILOT from a good idea for a scientific telescope to a strategic investment, the team made the argument that while the project was expensive, it could achieve results of equivalent scientific value to a space telescope, but at considerably lower cost. Colless explained that this was not necessarily true.

> *… calling it cheaper is arguable. It’s certainly cheaper than, say, launching the Hubble Space Telescope into space, but on the other hand I can launch a small cube sat into space cheaper than I can put an equivalent telescope down in Antarctica. And so the case was never quite as simple as they said, but they were ideologues on this point, and wanted to push it.*

The other logical problem with this argument was that Australia was not at that time planning to spend billions of dollars building its own space telescope, so PILOT was not in any sense a ‘saving’ for any portion of the national science budget. But the more complex and interesting reason that this argument falls down has to do with the way politics makes the relationship between money and ‘value’ non-symmetrical. As Colless framed the paradox, “maybe it’s 10 times cheaper than space, but unfortunately 10 times easier to get money to go into space, than it is to do stuff on the ground”. The feedback loop that makes some money ‘worth’ more than other money in this context might be called, in Colless’s spin on Eisenhower’s Cold War term, the “space industrial complex”. Governments spend more money on industries that advance their strategic interests than those that don’t, and over time, those military industries come to rely on continued government investment to prop them up, and in turn lend their support to governments who do so.

> *The government and industry have a little feedback loop going with each other. And the government feeds some more of the … your Lockheed Martin’s, and Grumman, and SpaceX’s and so on, and they then provide votes and support and technology and jobs for the government.*

In the US context, Colless explained that NASA's science budget is therefore out of proportion to their scientific activity. The organisation "has 16 billion dollars a year to spend on all these programs",

> *And they need to spend it, and so getting hundreds of millions of dollars, or a billion dollars for a space program is vastly easier than getting exactly the same amount of money for a ground-based telescope. Even if the ground-based telescope can do as much, or more, than the space-based telescope. […] That's not necessarily a bad thing. It doesn't have to be a bad thing, but it does distort … you know if you were doing … If you were trying to figure out how to spend your dollars to get the most science, that is not what you would do.*

What Colless points out so clearly here is that the dual-use nature of space technology is not just a passive designation that restricts exports and identifies utility to various players. Rather, it is also part of a complex economic cycle that continues to ensure its own existence. The catch is that only certain types of projects fit within the bounds of what will or won't be funded at any particular time.

The extent to which the space industrial complex has emerged in Australia is a question that will return in the next chapter. Travouillon thinks that there was a shift "less than five years ago" whereby advances in technology including laser communications and increased perceived need for space situational awareness (SSA) and space traffic management (STM) (both of which require accurate debris tracking) have increased the extent to which the space industry sees the value of collaborating with academic institutions on projects.

> *And so we are all using the same hardware now, can we work together, because you know, 'you want that, I want that', so again it's about leveraging, you know, more people … In science it's a big deal if you can get more support, if you are a bigger community and you all push towards the same goal, you get a lot more chance of getting funded, but if you're your lonely self in a university with no one else, waiting for someone to do … You can get a big team together, it's definitely better, and so by saying, "look I'm going to work with people in quantum physics to add a capability to my telescopes to do communications", for example, and communications they can lobby from my telescope, they are part of the game, they are part of the team, essentially. So it's never a negative thing.*

Yet curiously, and although Travouillon was not aware of it at the time, this is precisely what PILOT proposed to do with the little debris camera that Saunders had designed to image objects in orbit at the same time as PILOT was making astronomy observations. PILOT added one extra science case, and was going to provide data with which EOS might do "one extra thing". If Travouillon's sense that the change has occurred only in the last 5-10 years is correct, then PILOT was ahead of its time, perhaps in a way that disadvantaged it. While a younger generation of astronomers like Travouillon might have seen the dual-use aspect as a positive, it's possible that the older generation that reviewed PILOT as part of the ANSOC panel saw such a collaboration as, at best, irrelevant, and at worst, a negative.

Where Storey had viewed EOS as the organisation that would be contracted to build PILOT, Travouillon drew my attention to what role they might (or might not) have played in advocating for the project politically. He thought it possible that PILOT missed out on funding in part because EOS did not "push", and asked rhetorically, "was [the] EOS Board helping enough? Well maybe not, they didn't get funded". But Travouillon was quick to add that he didn't think that this was EOS's "fault". Instead, there has been a shift in the way that astronomy project proposals are run even in the decade that has passed between PILOT's unsuccessful NCRIS bid and Travouillon's current projects.

The core change, as Travouillon sees it, is how the astronomy sector in Australia engages with the notion (and reality) of dual-use technology: PILOT may have had a potential dual-use bolt-on project, but today's astronomy bids are more integrated.

At the time PILOT was being proposed, there was no space industrial 'machine' in the sense that there was no funding mechanism aside from NCRIS which could see the value of PILOT as a dual-use resource or as a scientific project in a way that tipped the value of the investment in its favour. Precisely how Dome C compared to Space as a location to put a telescope was an interesting piece of scientific knowledge, but Australia lacked the organisational structures to translate scientific information into significance for policy. Biddington acknowledged this deficit, framing it as short-sightedness on Australia's part, when he explained to me why Australia's Defence department "wouldn't have known what to do with [PILOT]". In his view, people in Defence who understood that there could be value to investing in space capability "didn't exist. They still almost don't".

> *You know, the number of people capable of having a space discussion in Defence, is tiny. And certainly a space policy discussion. There are lots of engineers, who know how to think about a waveform, or a widget on a satellite, or a satellite itself, but … get them thinking about policy, there's almost nobody there.*

Meanwhile, technology was moving forward rapidly. Whether or not EOS had the power to "leverage" on PILOT's behalf during the NCRIS process, the company's absence from documents pitching the PLT, PILOT's would-be successor, suggests that an Antarctic telescope was not of sufficient strategic value to the company to make continued involvement commercially worthwhile. The 'science case' for imaging objects in polar orbits might have been compelling in the 1990s and early 2000s, but by 2008, adaptive optics continued to improve and PILOT had rapidly become redundant. Even from a 'pure' science perspective, adaptive optics and space telescope technology have also both advanced rapidly in recent years, to the point that PILOT may not be worthwhile even today. According to Colless, even if PILOT had managed to deliver the sorts of results it claimed, and had proven itself to be a cost-effective wide-field alternative to a space mission, other projects are likely to rapidly take its place.

> *Now unfortunately the niche, that we were looking at, is about to be filled by people who have got money, you know, they're building quarter-of-a-billion-dollar satellites, WFIRST and so on, Euclid, which are doing the same thing: the wide field of view but with space quality imaging. And so that, the opportunity, the niche for something like PILOT is rapidly closing. And so it is not clear that it's ever going to be a viable thing to do.*[234]

Storey told me he'd recently made informal enquiries as to whether there might still be any strategic value for Australia in building a telescope like PILOT in Antarctica. He thought that the people he spoke to seemed "less impressed with that as an idea".

> *… their view was well "look, we know all about these satellites anyway, and we don't need to put a stupid telescope in stupid Antarctica to do it". Which may well be true, but certainly when we were talking about doing it a decade ago, it just seemed like a really sensible thing.*

One of the things that scuppered PILOT was simply time. Big projects like PILOT, led by academic institutions, take decades to eventuate. The military and private defence technology sectors move faster. From a corporate structure perspective, PILOT never became enmeshed with EOS in a way that might have pushed the EOS Board to throw their support behind the project. In the years

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[234] WFIRST stands for 'Wide-Field Infrared Survey Telescope'. The telescope has since been renamed the Nancy Grace Roman Space Telescope.

between when Storey first floated the idea of PILOT with Smith and Biddington and when PILOT actually came before a panel in 2008, it had slid into dual-use commercial obsolescence. Even setting the space industry players to one side, technological developments since 2008 may mean that the window in which a scientific case for a telescope on the Antarctic plateau could convincingly be made has already passed.

Thus, from a funding perspective, PILOT was a project out of step with its context. It was slightly behind the NCRIS process, still deeply embedded in the slow, meticulous consensus-building approach of the Decadal Plan, and too far ahead of its time for its value as a dual-use investment to be apparent to people who dealt in policy, not science. Simply put, PILOT had only the smallest window of opportunity to catch the very first ripples that hinted at the possibility of the wave that would become Australia's own space industrial complex.

3.3 Out in the Cold: PILOT forgotten?

> *… the Chinese took the idea and ran with it. And came up with KDUST, which was basically PILOT all over again.*
>
> **Matthew Colless, PILOT & SERC**

History tends towards accounts of things that happened, but my empirical study of PILOT, a project caught between funding mechanisms and industry changes, offers important insights for those attempting to understand the current state of the Australia space sector, as well as those interested in the academic study of failure. In this first telling of a history of PILOT, I used a combination of documented evidence and interviews with individuals who could provide firsthand accounts of their involvement with the proposal. From these sources, I pieced together in Chapter 2 a narrative retelling of those parts of PILOT's history that *did* occur, assembling the context of Australian involvement in Antarctic astronomy, and the scientific basis for the PILOT proposal, as well as the ways in which the funding structures for Australian scientific infrastructure were beginning to shift. I then described the technological design elements of PILOT, and how those working on PILOT's Phase A study sought to address the unique environmental challenges of the high Antarctica plateau. In doing so, I established two things: firstly, that PILOT did not fail on purely scientific grounds, because although elements of the theoretical design were contested, the Phase A study was ultimately successful in producing a credible technological design for an Antarctic telescope; and secondly, that the design itself, from the size and quality of the mirror to the inclusion of a debris-tracking camera, was indivisibly enmeshed with the surrounding political context at the time, which was sublimated into the NCRIS selection process through which PILOT would ultimately be rejected. I then traced in detail how the weight given to PILOT's little-known dual-use elements different significantly between individuals, and how the fact that this charismatic telescope only ever existed in imaginary form enabled the production of a variety of differing 'realities'.

In Chapter 3, I resisted a supernarrative about PILOT's failure to win funding, and instead drew on the legacy of scholars in the field of Science and Technology Studies (STS) to present a pluralistic account of the many contextual factors, most of them implicit, which contributed to PILOT's outcome. The analysis I assembled made it clear that the structural forces of Australia's astronomy funding landscape were always stacked against PILOT. Caught between funding regimes, none of which was really capable of meeting its logistical, technical, and financial needs, and faced with obstacles at every turn that ranged from the harsh Antarctic climate to what some might call the

Australian tendency to complacency, PILOT faded. At the same time, by providing a clear picture of all of these factors, I have assembled an empirically constructed snapshot of the Australian space funding landscape as it stood in 2008, within which I have shown precisely how the relationships between space debris, dual-use technology and astronomy were entangled, and how they were managed within the specific institutional relationships and structures of the time. From this concrete basis, in Chapters 4 and 5 I will juxtapose PILOT with a later project, SERC, which also grappled with dual-use technology and space debris. This kind of empirical study is vital because it provided a clear starting point to understand the ways in which political, economic, scientific, and social shifts have been reflected in the structure of Australian space science funding today, and how that in turn shapes the reality within which individuals and organisations carry out activities, and develop project proposals.

The analytic lens which best lent itself to the study of PILOT required that I approach PILOT as a kind of failure, which, I maintain, PILOT-the-proposal was. It did not receive funding and did not progress beyond a Phase A study. At the same time, as I assembled the complex layers of changing political interests in Antarctica and in observing space, my history of PILOT brought into relief a counter-narrative, which showed how, in the face of challenges, a group of individuals nonetheless persevered over more than a decade to try to bring their dreams of an Antarctic telescope into being. The involvement in my own, interpretive social science research project of some individuals who still believe in the scientific value of PILOT was driven, at least in part, by their desire for closure. They wanted to know why their efforts did not pay off. What my analysis has shown is that PILOT failed not on scientific or technological grounds, but because it was a proposal out of sync with its surrounding circumstances.

Storey described PILOT as the most “well-constructed, well-coordinated” iteration of “several attempts” he’d been involved with to propose an Antarctic optical infrared telescope. PILOT had been preceded by SPIRIT, the Douglas Mawson Telescope, and the Federation Telescope, none of which progressed to a Phase A study. It was immediately followed by the European pitch for the PLT, and the Chinese proposal for KDUST, both of which built on the work done by the PILOT design team, but neither of which have eventuated. It is not pure speculation to contend that the reason PILOT got as far as it did is not because it was well-constructed from a purely scientific standpoint, but because Storey, Biddington and others recognised that problems like that posed by space debris entailed the potential beginnings of a closer strategic relationship between space, international cooperation, and Australia’s national security interests — open questions, that PILOT could address. For a range of reasons to do with the social and political organisation of Australian space research rather than the project’s scientific prospects, PILOT was not exactly the right shape to fit neatly into the lock that was the funding system at the time.[235]

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[235] At the start of Chapter 2, I warned readers not to fall in love with PILOT. To anyone who finds themselves pining after the princess-telescope in the tower, I can offer no consolation. You were warned that PILOT would not be resurrected by academic study. Despite this careful reconstruction of PILOT-the-idea, PILOT-the-telescope is as non-existent as it ever was.

Chapter 4: SERC — a cooperative structure to manage space debris

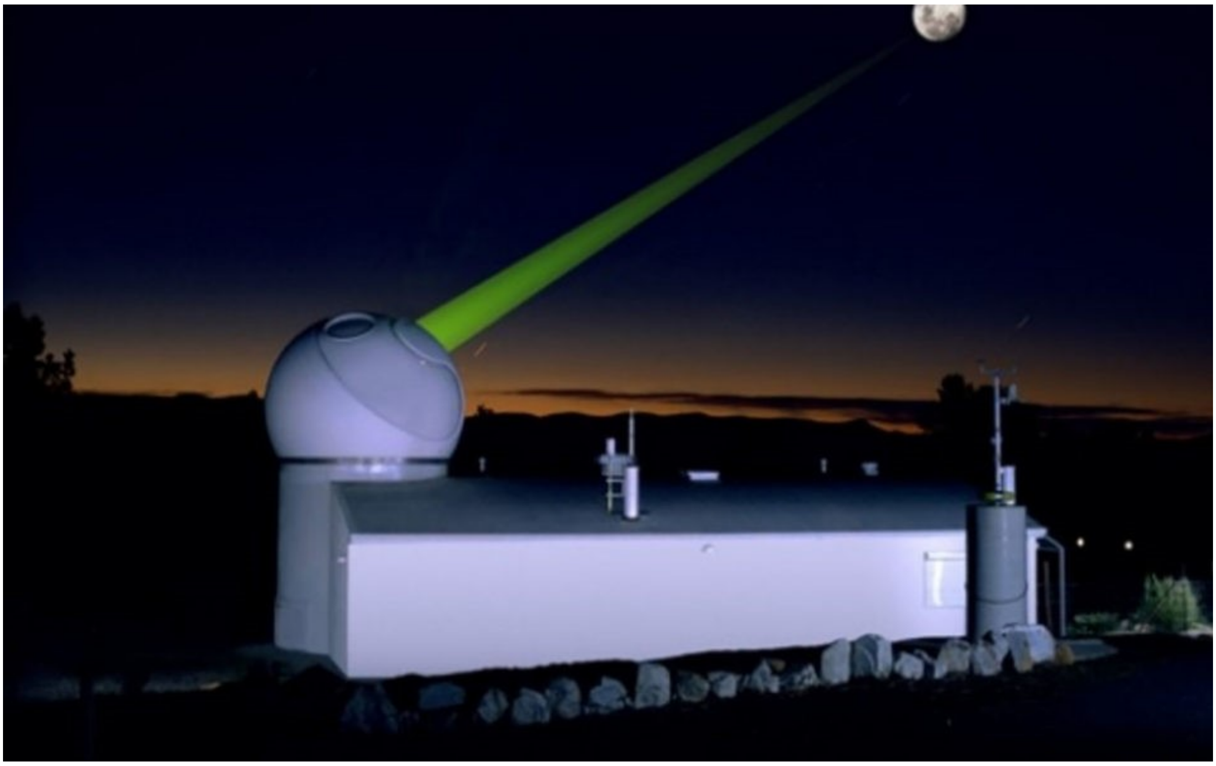

Figure 18 — Artist's impression of SERC laser in operation.[236]

4.1 The beginnings of SERC

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.[237] 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".[238] 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.[239]

The story of how the guide star laser was developed, and how EOS came to own the IP, is as much a story of economic, political, legal, and social structures as it is about technology. The Space Environment Research Centre (SERC), the banner under which this research was undertaken, began operations in 2014, was gradually wound up in 2020, and was formally de-registered in 2021.[240] It

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[236] (2015). Annual Report 2014 - 2015, Space Environment Research Centre.

[237] (2021). World-first Laser Developed to Blast Space Junk, Nine News Australia**:** 2:34., 0:26.

[238] (2021). "New Guide Star Laser Technology Developed."   Retrieved 14/05/21, from https://www.eos-aus.com/new-guide-star-laser-technology-developed/.

[239] Ibid.

[240] (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).

was an organisation called a Cooperative Research Centre or 'CRC', 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. In technical terms, 'SERC' refers to the company that operated what was officially called the 'CRC for Space Environment Management'.[241] 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.

While the development of guide star technology, and SERC generally, has been widely hailed as a 'success' in the Australian space sector and elsewhere, perhaps most particularly by EOS, a close analysis of publicly available sources combined with interviews conducted with individuals who worked on the project, from PhD students to Board members, reveals a more complicated picture. EOS may have a guide star laser that they did not have before, but the second part of the process, by which debris might actually be manoeuvred in space, has yet to be demonstrated. Put simply: for a range of technological, political, and legal reasons, SERC's stated goal — to move a piece of space debris in orbit using high powered lasers — failed. My research traces the many and varied failures of SERC, and most importantly, shows how these failures were recontextualised and reframed by interested parties into successes.

SERC was a complex project with many keenly interested stakeholders. What emerged quickly over the course of my research was that SERC would not be *allowed* to fail. Those with the desire and power to declare SERC a success would do so, and would select as evidence whatever would best support their conclusions. Over the several years I spent in SERC's orbit, the goalposts shifted so many times that it became impossible to determine what, if anything, might constitute a 'failure'. This was the magic of SERC. It was an organisation that consisted, in financial and structural terms, of very few individuals, and was therefore continually reconstructed by the social networks that embodied it. As an organisation, it was barely organised, and yet the institutions and individuals who formed it flowed around the problems they encountered — funding, technological failure, time, ethical objections — re-shaping and re-organising at every turn. SERC lacked transparency, continuity of key personnel, communication, and procedures, but people somehow carried on regardless. SERC constructed a post-failure reality within which to operate.

Where PILOT flirted with the idea of dual-use technology, SERC, although it carefully positioned itself from the start as a purely civil undertaking (i.e. carrying out the moral and practical imperative of cleaning up space) was a dual-use entity. Philosopher of technology John Forge offers a definition of dual-use as applying to knowledge, technology or an artefact "if there is a (sufficiently high) risk that it can be used to design or produce a weapon, or if there is a (sufficiently great) threat that it can be used in an improvised weapon, where in neither case is weapons development the intended or primary purpose".[242] He argues that, in the course of assessing whether something is dual-use, risk, threat and values are contextual factors that must be taken into account.[243] To apply Forge's analytic framework, 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'. After all, the 'Achievement Snapshot' published by SERC is quite explicit that the guide star laser whose

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[241] (2015). Annual Report 2014 - 2015, Space Environment Research Centre. p. 7.

[242] Forge, J. (2010). "A Note on the Definition of "Dual Use"." Science and Engineering Ethics **16**(1): 111-118. p. 117.

[243] Ibid. p. 117.

development SERC supported “has applications across both civilian and defence sectors and will position EOS to bid for tenders after SERC has wound up”.[244]

As Forge notes, research which gives rise to dual-use technology is also dual-use, irrespective of whether the researcher realises this at the time.[245] This raises moral and administrative problems for researchers and institutions.[246] It is this very awkwardness — these moral and administrative challenges, and how they are navigated by individuals and institutions — that motivates my research. By its existence, SERC encapsulates the fact that the ways that ‘civil’ and ‘military’ are divided, particularly in the context of space sciences, mainly rhetorical. The gap suggested by the hyphen that sits between the ‘military’ and the ‘civil’ in discussion of ‘military-civil cooperation’ suggests the existence of a gap between the two that is not borne out by the organisational practice of knowledge production — but, or so I argue, SERC as an institution works to stabilise the rhetoric of such a gap. This chapter 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, structuring individual and institutional moral responsibility (almost) out of existence. It also provides a starting point from which to consider the sorts of questions that Forge raises about moral responsibility. Without this sort of empirical research, it is impossible to begin the next step of deciding whether this is how things ought to be, or how they might be done better.

The concept of ‘dual-use’ is not new, but what my research does is make apparent and analyse the structures in which people do research and engage with these entanglements in practice. This chapter outlines how SERC arose from a pre-existing research partnership between ANU’s Research School of Astronomy and Astrophysics (RSAA) and EOS Space Systems, and how 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. It then examines how a diverse range of scientific and industrial interests were brought together and enacted through its specific research, corporate, financial, and social structure.

4.1.1 CRCs: funding structures across academic and industrial sectors

SERC was originally formed through a funding structure called a CRC, which, importantly for my analysis, is an Australian policy and funding model which specifically aims to create industrial-academic hybrids. Cooperative Research Centres were brought into Australian national policy in 1991,[247] around the same time that Townes negotiated the declassification of US military adaptive optics research,[248] and that Storey was becoming interested in Antarctic astronomy. The CRC program was designed by Chief Scientist Professor Ralph Slatyer,[249] as “the institutionalisation of

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[244] (2021). Achievement Snapshot, Space Environment Research Centre. p. 10.

[245] Forge, J. (2010). "A Note on the Definition of “Dual Use”." Science and Engineering Ethics **16**(1): 111-118. p. 113.

[246] Ibid. p. 111.

[247] 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.

[248] See Finkbeiner, A. (2006). The Jasons: The Secret History of Science's Postwar Elite, Penguin Publishing Group. Chapter 7.

[249] 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.

cross-sector collaboration in R&D”.[250] 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”.[251] Today, the CRC program sits within the purview of the Australian Government Department of Industry, Science, Energy and Resources.[252] 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 January 2008, as dreams of PILOT were fading, the Federal Minister for Innovation, Industry, Science and Research announced a Review of the Australian Cooperative Research Centres (CRC) Program.[253] Appointed to conduct the review, distinguished scientist Mary O’Kane’s report ‘Collaborating to a Purpose’ briefly summarises the benefits of the CRC program, while noting the point foregrounded in the report’s title: “collaboration should not be an end in itself”.[254] The benefits cited include:

> *… the achievement of critical mass; overcoming fragmentation caused by distance and a smaller resource base; bringing together different perspectives, experience, skills, and knowledge, breaking down specialist silos and restrictive organisational boundaries and fostering cross-disciplinary interactions; encouraging skills and knowledge transfer; promoting mutual understandings; and managing risks.*

Despite their name, Cooperative Research Centres are neither “’cooperatives’ in the sense of being member-based, democratically controlled organisations”,[255] nor are they necessarily physical ‘centres’. Instead, the CRC policy aims to produce collaborations between research institutions and the private sector that are structured into new entities. They receive government funding in order to achieve a stated goal considered to be of value in generating “productive and innovative outcomes for both the collaborators and the taxpayers whose funds are invested in the Program”.[256]

Numerous scholars and analysts, including O’Kane, have assessed the efficacy and operation of the CRC as an entity from a policy, economic, or organisation standpoint. Sociologists and policy researchers Tim Turpin and Sam Garrett-Jones’s work (2011) considers CRCs from a participant engagement and outcomes perspective, examining the impact of CRCs on academic careers and the implications of their structures for human resource management approaches.[257] Policy and public

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[250] 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.

[251] 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.

[252] (2021, 19/05/21). "Cooperative Research Centres." Retrieved 21/05/21, from https://www.industry.gov.au/funding-and-incentives/cooperative-research-centres.

[253] 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.

[254] Emeritus Professor Mary O’Kane is a noted Australian scientist and engineer who had extensive prior involvement in CRCs, both from a policy and practical standpoint. Ibid. p. 77 and p. xi.

[255] 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. 95.

[256] 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.

[257] Turpin, T. and S. Garrett-Jones (2010). "Reward, Risk and Response in Australian Cooperative Research Centres." International Journal of Technology Transfer and Commercialisation **9**(1/2): 77-93. See also Turpin,

administration scholars Elisabeth Sinnewe, Michael Charles and Robyn Keast's 2015 paper "Australia's Cooperative Research Centre Program: A transaction cost theory perspective" assesses the success of the CRC program at an organisational level "to determine the impediments to long-term sustainable collaboration between industry and academia".[258] Research education policy advisor Nigel Palmer's 2012 report to the Cooperative Research Centres Association (CRCA) looks specifically at 'graduate outcomes' for students who come through a CRC pathway.[259] More recently, in 2014, Australia's Minister for Industry and Science commissioned another review of the CRC Program "to consider whether it is the most appropriate vehicle to support business and researchers to work together to develop and transition to Australia's industries of the future".[260] Like O'Kane's 2008 report, the 2015 report provided to the Minister on CRCs recommended their continuation with small changes: in this case, "a new, more targeted focus".[261]

In contrast to these assessments of CRCs as organisational vehicles which measure their success in terms of how well they achieve the goal of accelerating research and promoting cooperation, my aim is to document how the CRC program implements its programmatic blurring of the boundaries between scientific research and commercial activity, and to what effect. I examine how funding, policy, and organisational structures create spaces within which both new technologies and participants' actions and thoughts take shape. What better CRC for this purpose than one whose founders chose as chair of their Board Professor Mary O'Kane herself: The Space Environment Research Centre.

4.1.2 Partnership between ANU and EOS

On 18 January 2003, while Travouillon, Lawrence and Storey were installing their AASTINO at Dome C, 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.[262] While the 2003 fire was not the first to impact the site,[263] which had been formally established in 1924 and transferred to ANU in 1957,[264] the impact on the community was profound. The 2003 fire was unprecedented in the scale of physical destruction it caused.[265] 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

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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.

[258] Sinnewe, E., M. B. Charles and R. Keast (2016). "Australia's Cooperative Research Centre Program: A transaction cost theory perspective." Research Policy **45**(1): 195-204.

[259] Palmer, N. (2012). The CRC Contribution to Research Training: Report of a Scoping Study for the Cooperative Research Centres Association. Canberra, Australia, Cooperative Research Centres Association.

[260] Miles, D. (2015). Growth through Innovation and Collaboration: A Review of the Cooperative Research Centres Programme.

[261] Ibid. p. 7.

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

[263] 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/.

[264] 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.

[265] 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.

Mount Stromlo's facilities.[266] 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.[267] 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".[268]

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).[269] 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.[270] This, as discussed previously, contributed to the conditions that led to Astronomy Australia's decision to use NCRIS funds to purchase an additional 5% share in the GMT-DDP, rather than proceed with PILOT. 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".[271] Biddington recalls that 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.[272] 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.[273]

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),[274] and EOS to construct and operate a new satellite laser ranging system on the site.[275] 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,[276] and

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

[267] (2005). Annual Report 2005, ANU Research School of Astronomy & Astrophysics. p. 66.

[268] Ibid. p. 66.

[269] (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.

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

[271] Ibid. p. 267.

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

[273] 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.

[274] (1998). Customer Service Charter. Australian Surveying & Land Information Group. P. Holland.

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

[276] Ibid.

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.[277] Previously, space debris tracking had to be done using radar, which was less accurate.[278] 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".[279] 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".[280]

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'.[281] 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".[282] 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".[283] 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",[284] to "modify the orbit of space debris using a ground based adaptive optics (AO) corrected laser".[285] Adaptive optics were necessary because compared to a telescope positioned at, say, Dome C, which had naturally calm atmospheric conditions due to its latitude, altitude, and climate, the 'seeing' at Mount Stromlo, which did not have these natural advantages, was significantly worse. 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

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[277] (2018). With EOS We're Working with Business and Satellite Technology. Research Stories, ANU Research School of Astronomy and Astrophysics.

[278] Ibid.

[279] (2010). Annual Report 2010, Electro Optic Systems. p. 4.

[280] Ibid. p. 4.

[281] 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.

[282] Ibid. p. 1.

[283] Ibid. pp. 1-2.

[284] Ibid. p. 1.

[285] 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**.

capabilities delivering laser energy to small targets at extreme distance".[286] Where PILOT proposed to image debris (and other objects) orbiting overhead, and the Adaptive Optics Demonstrator (AOD) had applied adaptive optics to laser technology to improve the predictive capabilities of debris tracking,[287] the 2009 business update goes further, discussing the possibility of using lasers for "laser ablation", "theatre defence", and "missile defence".[288] 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".[289] 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".[290] 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",[291] 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.*[292]

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".[293] 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.

In 2012, Biddington recalls a phone call from Greene, who pitched the idea of proposing the laser ablation project as a CRC. The natural choice would be for EOS and RSAA to continue to work together, supplemented by team members from other institutions and 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, with three Independent Directors appointed: O'Kane, Biddington, and Elizabeth Whitelaw.[294]

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[286] (2009). EOS Defence Business Update. Canberra, Electro Optic Systems Holdings Limited. p. 2.

[287] 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.

[288] (2009). EOS Defence Business Update. Canberra, Electro Optic Systems Holdings Limited. p. 2.

[289] Ibid. p. 2.

[290] Ibid. p. 2.

[291] Ibid. p. 3.

[292] Ibid. p. 2.

[293] Ibid. p. 3.

[294] (2015). Annual Report 2014 - 2015, Space Environment Research Centre. p. 7, p. 29.

The CRC at Mount Stromlo that emerged from this collaboration between EOS and ANU opened as the Space Environment Research Centre (SERC) on 1 July 2014.[295] In November 2014, two additional directors were appointed to the board: Steve Gower, then the Director of Research Collaborations and Partnerships at RMIT University became SERC's Research Director, and Rod Drury, a senior employee at Lockheed Martin Space Systems Company (LMC) became SERC's Industry Director and Chief Operating Officer (COO).[296] In addition to his role as CEO of EOS, Greene took on the role of SERC CEO and Chair of the SERC Research Management Committee,[297] while Craig Smith, CEO and Technical Director of EOS Space Systems, became SERC's Company Secretary.[298]

Key to SERC's branding, mandate, and operations was the way in which the team actively shaped the narrative. Space debris was framed as an environmental and commercial threat, and SERC as a viable solution to a pressing issue. Quoted in a long-form article published by the Australian Broadcasting Corporation (ABC) in 2014, which announced SERC's formation, Craig Smith described debris as an "environmental problem", a type of orbital pollution, "kind of like the way we've polluted oceans and rivers".[299] In the same article, Greene invoked the Kessler effect, a theoretical tipping point proposed by NASA scientists Cour-Palais and Kessler in 1978,[300] saying:

> *A catastrophic avalanche of collisions that would quickly destroy all satellites is now possible. In the worst case, two satellites would collide and the debris from those satellites would be directly in the path of more satellites in a very short space of time. They would then generate more debris and very quickly the avalanche would grow until everything was colliding with everything and space would become uninhabitable for satellites for hundreds of years.*[301]

Importantly, SERC was positioned from the start as a civil, non-military, undertaking. Having framed space as an environment in need of 'cleaning up', EOS had created the moral and practical imperative to develop high power laser technology, and seek academic partnerships and government funding to do so.

4.1.3 Formation of the SERC CRC

Steve Gower, who became SERC's Research Director, had completed his PhD through a CRC and had, by this time, sat on numerous CRC boards.[302] He understood that forming the right partnerships at an organisational level, domestically and internationally, was critical. The partnership that formed was international and diverse, including EOS Space Systems, ANU, RMIT, Optus Satellite Systems, Lockheed Martin US, and the Japanese National Institute of Information and Communications

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[295] Ibid. p. 7.

[296] Ibid. p. 30.

[297] Ibid. p. 32.

[298] Ibid. p. 33, p. 30.

[299] 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.

[300] Kessler, D. J. and B. G. Cour-Palais (1978). "Collision Frequency of Artificial Satellites: The Creation of a Debris Belt " Journal of Geophysical Research **83**(A6): 2637-2646.

[301] Smith, C. and C. Kimball (2014). New Australian Research Centre to Remove Space Junk, Save Satellites and Spacecraft. ABC News, ABC.

[302] Gower, S. (2020). Research Interview. HREC 2020/145. A. Handmer.

Technology (NICT), which had a long history of working with Australia on laser tracking.[303] In his capacity as EOS's CEO, Greene wrote in his Review of Operations in the 2013 EOS Annual Report that the CRC would receive "around $60 million over 5 years", which included $20 million from the Australian Government.*[304]* Although Greene confirmed that SERC was a "completely separate research activity from EOS commercial space activities", he anticipated that there would be impacts on those commercial activities down the track.*[305]*

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.[306] 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.[307]

The specifics of how technology, information, and money would flow under the agreement was important for international partners. Biddington explained that while the involvement of Lockheed Martin US brought with it challenges regarding export controls laws, it was necessary because the Australian offices of Lockheed were primarily sales and presence offices, with the company's substantive operations, including Lockheed Martin Space Systems Company, headquartered in the US. As a private entity, Lockheed managed to find ways to make their participation work, but other foreign government bodies found it more difficult. Japanese law, for example, required that involvement from NICT was limited to non-military aspects, so Gower recalls that the Participant agreement had to be drafted with "a specific clause that said they would be on non-military associated work".

For one organisation, the challenges proved to be insurmountable. Initially, the CRC had included a team from NASA Ames Research Center. NASA had conducted a major study, 'Project ORION', in 1995, in collaboration with the US Air Force Space Command to assess "the feasibility of removing the bulk of the threatening orbital debris in low-Earth orbit (LEO) by irradiating it with a ground-based laser".[308] The technical memorandum published in 1996 concluded that it was possible to exert "a small but significant momentum change" on a debris particle using a "sufficiently intense laser beam", and that a series of such ablations "delivered at well-chosen times and positions, can change the particle's orbit and cause it to reenter [sic] sooner than it would otherwise".[309] However, while the report concludes that the proposed method of debris removal is "feasible",[310] the telescope and laser required to perform the task at the time the study was carried out were "technologically challenging and prohibitively expensive".[311] 15 years later, researchers from NASA Ames Research Center hypothesised that contemporary technology might now be up to the task,

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[303] (2016). Annual Report 2015 - 2016, Space Environment Research Centre. p. 54.
[304] (2013). Annual Report 2013, Electro Optic Systems. p.4.
[305] Ibid. p.4.
[306] Gower, S. (2020). Research Interview. HREC 2020/145. A. Handmer.
[307] (2015). Annual Report 2014 - 2015, Space Environment Research Centre. p. 7.
[308] Campbell, J. W. (1996). Project ORION: Orbital Debris Removal Using Ground-Based Sensors and Lasers. Technical Memorandum. Alabama, USA, Marshall Space Flight Center. p. 2.
[309] Ibid. p. 4.
[310] Ibid. p. 36.
[311] Mason, J., J. Stupl, W. Marshall and C. Levit (2011). "Orbital Debris–Debris Collision Avoidance." Advances in Space Research **48**(10): 1643-1655. p. 2.

proposing “a 5-10kW continuous wave laser mounted on a fast slewing 1.5m optical telescope with adaptive optics and a sodium guide star, which allows the laser beam to be continuously focused and directed onto the target throughout its pass”.[312] ANU RSAA and EOS Space Systems in turn suggested that the EOS telescope (1.8m) could be used in combination with a 10kW laser and an adaptive optics system to test what had, up to this point, been purely a theoretical discussion.[313] As of 2014, NASA Ames Research Center was on track to collaborate officially as a SERC partner,[314] but they pulled out “at the 11th hour”. Gower explained that throughout the course of SERC’s operation, “bureaucracy got in the way” of technological and financial exchanges between SERC and NASA, because SERC, registered in Australia, was classed as a “foreign agent”.

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”,[315] 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.[316] 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”.[317] 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.[318]

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, in a way that never happened for PILOT. SERC took on an “identity”,[319] 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,[320] 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.[321] 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.[322]

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[312] Ibid. p. 2.

[313] 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. 1.

[314] 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.

[315] (2016). Annual Report 2015 - 2016, Space Environment Research Centre. p. 53.

[316] Ibid. p. 54.

[317] Ibid. p. 54.

[318] Ibid. p. 55.

[319] (2015). Annual Report 2014 - 2015, Space Environment Research Centre. p. 26.

[320] Ibid. p. 26.

[321] Ibid. p. 8.

[322] Ibid. p. 8.

With O'Kane overseas, Biddington stepped up to give a speech on behalf of the SERC Board. Biddington's wording appears carefully crafted to speak equally to those from a civil science background and those with more strategic interests. This was one of SERC's most remarkable feats: it managed to maintain perfect ambiguity between whether 'space environment' referred to space as a strategic domain, or whether the phrase was intended to be read in ecological terms. This ambiguity allowed each person, bringing their own context, knowledge, and biases, to see in SERC either or both, according to their preference. Biddington's speech perfectly encapsulates this duality. He begins by establishing clear stakes — that Australia "has critical dependencies on space technologies", and notes that space is "increasingly contested, congested and competitive".[323] In the same breath, Biddington expresses that the "space environment is fragile", "cluttered with space debris". He goes on to state explicitly that "space is a dual use domain", which "remains the high ground of warfare as well as providing critical infrastructure that is vital to the economic and environmental health of all nations".[324] Such deliberate and careful framing of SERC, particularly in media mentions, remained a priority for those in management positions throughout its five years of operation.

The second important thing that Biddington's speech did was to differentiate SERC from other CRCs on commercial terms, by setting up SERC as an "industry led" business venture rather than merely a research organisation. Where other CRCs pooled resources and expertise, SERC's "heritage", years of collaborative research between EOS, ANU and RMIT, had established "basic trust and understanding", the "foundation for any successful business enterprise". SERC would take "an explicit commercial approach in order to squeeze every ounce of value from the funds provided by the Commonwealth without actually imposing commercial standards that can lead to short termism, on the research itself".[325] SERC was a hybrid, chimeric creation, which, even in retrospect, evades attempts to draw definitive boundaries between what it was and what it was not. SERC meant different things to different people, and importantly, it was backed by industry, academia, public service, and politics. Now all that was left to do was figure out how to move debris with a laser.

Figure 19 — SERC's logo was described in the inaugural annual report as being an image that "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". [326]

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[323] Biddington, B. (2014). Opening Remarks on the Occasion of the Official Opening of the Space Environment Research Centre (SERC). Parliament House Canberra, 2 December 2014. (Materials provided by Biddington for my research, HREC 2020/145).

[324] Ibid.

[325] Ibid.

[326] (2015). Annual Report 2014 - 2015, Space Environment Research Centre. p. 26.

Figure 20 — SERC Launch official signing with NICT, featuring (left to right) Dr Hiroo Kunimori (Senior Researcher, NICT), Dr Fumihiko Tomita (Vice President and Chief Research & Strategy Officer, NICT), Senator Ian MacFarlane (Minister for Industry and Science), Brett Biddington, and SERC and EOS CEO Dr Ben Greene.[327]

4.2 Structuring a chimeric entity

> *… if you set up an interdependency amongst all your team members, then it's the best way to get results out of someone you don't have control over.*
>
> **Steve Gower, SERC**

4.2.1 Unification: identifying goals and outputs

SERC may have been a formality, restructuring an existing partnership to meet requirements for government funding, and it may also have been a deliberately ambiguous and slippery concept, but the formation of an entity brought with it a public and private conversation about outputs: what would SERC aim to achieve, and for whom?

One place to look is in the official register of CRCs published by the Australian Government Department of Industry, Science, Energy and Resources. In 2020, that register stated that the objective of the 'Space Environment CRC' was "to monitor, analyse and manage space debris and develop new technologies and strategies to preserve the space environment for the benefit of Australia".[328] Another source of information is the inaugural Annual Report, in which Greene writes that SERC "was established to preserve access to the space environment". [329] In line with this goal, SERC had "two specific research objectives": the first, to "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", and the second, "to manoeuvre space debris away from collisions using lasers on the earth".[330]

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[327] Ibid. p. 27.

[328] (2020). CRCs Over Time. Cooperative Research Centres (CRC) Program. Australian Government Department of Industry, Science, Energy and Resources. p. 14.

[329] (2015). Annual Report 2014 - 2015, Space Environment Research Centre. p. 6.

[330] Ibid. p. 6.

In addition to SERC's official, organisation goals, each individual partner organisation had their own specific objectives. For Colless, as the Director of ANU Research School of Astronomy and Astrophysics (RSAA), the goal was to progress the science and technology that EOS and ANU had already been working on, towards "commercial outcomes". However, while Colless explained that RSAA would be "happy to take brownie points", they "weren't really expecting to get direct money from that". Instead, he hoped for "IP and new technology and ideas we could apply to astronomy". More significantly, Colless pointed out that when assessing opportunities like SERC, it was important to consider "how they will not only be successful in themselves, but how they will connect to other things, to allow you to leverage success in other areas". Thus, the actual on-sky laser experiment (pushing a piece of debris using a laser) might have delivered technological and scientific advances, but Colless also had an eye to how any CRC or centre would fit "into a larger strategic pattern for an organisation". As he put it, "you are always looking for overlaps and is this thing doing more than its own goals".

One such side-benefit Colless hoped would arise from SERC was ongoing commercial contracts with EOS. The ANU RSAA had a history of doing "commercial work in partnership with EOS", where EOS would subcontract work from one of their contracts to members of the RSAA team. From an organisational standpoint, such contracts were a useful source of funding to the institution. Colless explained:

> *… we just, you know, get the money, and that's great, it keeps employed some of our people, and we can take any profit we make and plough it back into our research. So that's fine. We are very happy to do that.*
>
> *We've got a whole arm of our school, the Advanced Instrumentation and Technology Centre, that is basically quasi-commercial. Although it does all these sorts of projects, it has to mostly supply its own funding, because it is now way too big for us to be able to support it from just the university's earnings. And so most of the AITC's money comes from grants and contracts that it runs and operates, which funds its own activities.*

In this sense, "the CRC was just another grant, like an ARC LIEF grant, or like an external commercial contract".

Providing context for the popularity of the CRC structure more broadly, Gower felt that dwindling sources of government funding for scientific research historically had affected the activities and structures of universities, and incentivised this kind of hybrid academic-commercial model. Colless and others at RSAA were keen to expand their team's commercial capability and track record in the space industry so that they could attract more funding opportunities, especially in the context of "'space' in the 'near earth orbiting satellites' sense rather than in the 'beginnings of time, Big Bang' space sense". SERC would build on existing capabilities in satellite manufacture and testing and provide RSAA and the AITC with an opportunity to broaden their capability into growing areas like Space Situational Awareness.

Colless's perspective was informed by his position and responsibilities, as well as the social and institutional structures in which he operated. His characterisation of the expected outcomes of SERC therefore differs significantly from the view of someone sitting outside of his particular institutional context. For Biddington, for example, the outcomes he hoped SERC would achieve were improving Australia's sovereign capability in terms of human capital, equipment, and knowledge in the area of space situational awareness and related fields. In discussion, he pointed to the number of PhDs that SERC aimed to 'put through'. Gower, on the other hand, coming in with a mind to the business and technical operations of the CRC, explained that in order to receive funding, SERC had to be in

Australia's national interest, "generally aligned with growth centres, industry growth centres, or national research priorities". Within this context, Gower characterised SERC's goals as being on the one hand to develop "technology and techniques to better detect space junk", ultimately leading to tools that were useful to satellite operators, and on the other hand to bring together mathematical and technological elements to carry out the remote debris manoeuvre experiment.

To Travouillon, who joined SERC in 2018 "as a project manager, not of the overall thing, but all of our engineering activities, essentially", the goal of SERC was less about the lasers and telescopes, and more about taking advantage of Australia's geographic location ("prime real estate") to contribute constructively to "a crisis that we need to solve". As he went on to explain, orbits are becoming "crowded" with debris, and "space is difficult because it doesn't belong to anybody, it's international, it's nobody's responsibility but everybody's business at the same time". For him, SERC's proposed activity, "monitoring, and essentially affecting those debris", was not only a technological achievement, but "a matter of national pride and national accountability as well".

Francis Bennet, on the other hand, an ANU instrumentation scientist who worked on the physical technology underpinning SERC's activities, had a different take.[331] As a researcher, Bennet generally seeks tangible outputs ("KPIs") such as "research publications" (papers or conference presentations), "patents or IP", and contracts and grants for ANU that would be "self-propagating" in terms of bringing in further funding. Speaking about SERC specifically, Bennet differentiated between the technical goal ("to push a piece of space debris") and the "other, political goals, which have changed year to year". He drew my attention to the role SERC has played in the national conversation about space — a conversation that was continually developing over the time that SERC operated.

> *So I mean, it started out as just being advertising for SSA [Space Situational Awareness], and what EOS could do. I think that's changed more into a national story, and — to try and drive national priorities. I mean, SSA is one of the priority areas of the Australian Space Agency. So, I think it's interesting that … SERC certainly would have had a hand to play in that. Because I think without it, while there are a lot of other activities going on in Australia, in terms of SSA, I think SERC stood out, certainly on the optical front … and on the scale. I mean, there hadn't been anything of that level of funding, for SSA, previously.*

Depending on your perspective, SERC was about national pride, technological development, upskilling a workforce, or securing funding for future research. Of course, SERC was about all of these goals, and countless more. The structural organisation of these individuals and institutions had to balance all of these differences in priorities and perspectives, while driving towards the overarching technological goal — pushing a piece of space debris in orbit with a laser.

4.2.2 SERC's research and organisational structure

In terms of its research structure, SERC was initially organised as a single research project, which sat on top of four interlinked research programs, the outputs of which combined together to support the overarching goal of the debris manoeuvre experiment.[332] Research Program 1, titled 'Tracking, Characterisation and Identification of Space Objects',[333] was initially led by EOS Space Systems' Craig Smith. It aimed to develop "solutions for reliable and accurate observation and tracking of space objects, better monitoring and cataloguing of space debris, orbit conjunction analysis and collision mitigation".[334] As Bennet put it, Research Program 1 "was all about improving the accuracy of the

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[331] Bennet, F. (2020). Research Interview. HREC 2020/145. A. Handmer.

[332] (2015). Annual Report 2014 - 2015, Space Environment Research Centre. p. 12.

[333] Ibid. p. 12.

[334] Ibid. p. 12.

measurements. So it was all about what size and shape is the object in orbit? Can you improve the ranging to it with adaptive optics?". At a technological level, the program worked on enhancing the capabilities of two adaptive optics systems. Bennet explained that one would operate with EOS's 1.8m telescope at Mount Stromlo, and the other, "upgraded from the previous collaboration", would be used for debris laser ranging. Research Program 2, led by Professor Kefei Zhang, Director of the RMIT University SPACE Research Centre, was called 'Orbit Determination and Predicting Behaviours of Space Objects'. Its goal was to develop "new tools to improve the accuracy and reliability of orbit predictions, including the development of new models for space weather and earth gravitational field influence".[335] Research Program 3, 'Space Asset Management', was led by Dr James Bennett, one of the few researchers working within the CRC who was employed directly by SERC.[336] The purpose of Research Program 3 was to develop "techniques, algorithms and databases to assist in predicting and thus avoiding potential collisions in space".[337] The final program, Research Program 4, was called 'Preservation of the Space Environment'.[338] Originally led by Greene, in addition to his role as SERC CEO, its goal was to develop "technologies to mitigate the deterioration of the space environment due to debris-on-debris collisions by using lasers to manoeuvre debris in space".[339] Francis Bennet, who worked on this team, explained that it was originally "just basically the instrument and the demonstration", but that the focus of the program shifted during the course of SERC's operation.

While it seemed at first glance that the most challenging aspect of SERC would be the technological complexity of conducting a demonstration that had never been done before, it emerged through the course of research and discussions that one of the most difficult elements was actually navigating SERC's unique organisational structure, which was distinct from the research structure. Sitting around the research programs and CRC participants were administrative, professional, and research staff, employed by SERC, who had the job of running SERC as a company. From the outset, SERC was registered as a charity with the Australian Tax Office, rendering it exempt from income tax, but there were still complex and strict reporting requirements to comply with.[340] In addition to managing incoming grant funding and participants' in-kind contributions and reporting progress to all participants, CRCs in Australia are also required to report regularly (usually quarterly) to the Commonwealth government agency managing the CRC program, in addition to producing an annual report and an end of project report.[341] All SERC-specific reporting came in addition to whatever internal governance processes each participant organisation already had in place.

The onerous reporting requirements to which CRCs are subject is a theme that is prominent in both the O'Kane review (2008) and the Miles review (2015). O'Kane's report notes "a consistent and frequently mentioned theme throughout the submissions and the consultations was that of the complexity and cost of CRC governance arrangements".[342] In 2015, the Miles review recommended

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[335] Ibid. p. 12.

[336] Dr James Bennett should not be confused with the aforementioned Dr Francis Bennet.

[337] (2015). Annual Report 2014 - 2015, Space Environment Research Centre. p. 12.

[338] Ibid. p. 12.

[339] Ibid. p. 12.

[340] Ibid. p. 28.

[341] (2020). Commonwealth Standard Grant Agreement. Cooperative Research Centres Program Round 21/Round 22. Australian Government Department of Industry, Science, Energy and Resources. p.9.

[342] O'Kane, M. (2008). Collaborating to a Purpose: Review of the Cooperative Research Centres Program. Canberra, Dept. of Innovation, Industry, Science and Research. p. 57.

formally that “the application, selection, reporting and administrative requirements for each stream of the programme should be simplified and streamlined”.[343]

In 2009, the sociologists and policy researchers Tim Turpin and Sam Garrett-Jones compiled surveys conducted in 2005 with 370 individuals from public sector organisations about their experiences individually and institutionally of working within a CRC structure.[344] A common theme that emerged was a view that CRCs involved “unnecessary” and “onerous” administrative overheads.[345] The paper explains this attitude as arising from two core reasons. The first was that “respondents saw little benefit flowing back to themselves or their research groups” from completing administrative requirements.[346] The second was that respondents felt that “politicking and management distracted them from their main concern of carrying out research”, both from a financial and conceptual standpoint.[347]

Gower, aware of these common complaints and pitfalls, explained that SERC “started out with the view to funnelling as much funding as we could into research, not into administration”. Whereas in most CRCs “50% of the cash that comes from the participants and government (18.07) goes to research, and 50% goes to admin”, SERC aimed to spend only 25% to 30% of all funding on administration: “employing media people, comms, admin staff, finance managers, research program leaders, CEOs, CFOs, employing the board, company secretary, all that sort of stuff. And the office administration and corporate governance style of stuff”. Yet despite SERC’s ambitions to be efficient and streamlined, and although their project commenced a decade after Turpin and Garrett-Jones did their research, during which time the government had commissioned a number of reviews and enacted recommended policy changes, there are striking similarities between the responses from those surveyed in 2005 and comments made by those I interviewed about SERC for this research.

Travouillon, for example, who came into SERC in 2018 to project manage the technical side of the program, found the “weird organisation of SERC” difficult to navigate. He explained that it was challenging to get “a bunch of administrators, working not necessarily very well with the different stakeholders like ANU, and EOS” to work together at the same pace and keep technical deliverables on track. The problem was compounded by the “different rules” by which people at different organisations worked. The issue, as he saw it, was structural, rather than down to individuals.

> *… so this structure, in the end, I am not a big fan of and I don’t think anybody was a big fan of, because instead of having two bodies, where you had EOS and ANU working together, you had this third branch, the SERC administration, which kind of didn’t really help us. It kind of made things more opaque. It added a level of administrative complexity where we didn’t get anything out of it, in terms of help and management, like I was saying earlier. It was a layer that was more of a burden than help.*

Sitting within this “third branch” was Gower, responsible for compiling the required reports on SERC’s activities, spending, and progress, which included monthly reports to the Board. He described, from his experience, the challenges that arose as he tried to meet the “large overheads in reporting” (illustrated in Figure 21). He tried to streamline the process through the use of a

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[343] Miles, D. (2015). Growth through Innovation and Collaboration: A Review of the Cooperative Research Centres Programme. p. 12.

[344] Turpin, T. and S. Garrett-Jones (2010). "Reward, Risk and Response in Australian Cooperative Research Centres." International Journal of Technology Transfer and Commercialisation **9**(1/2): 77-93. p. 10.

[345] Ibid. p. 14.

[346] Ibid. p. 15.

[347] Ibid. p. 15.

proforma, which included all reporting requirements for the Board as well as for official government reporting. The proforma asked participants to fill in progress made against milestones that had been specified in their agreements. In addition, the administrative team had to keep track of inputs and outputs, such as in-kind contributions, research publications, and development of intellectual property. Gower explained:

> *… So then I've got a master spreadsheet, where all that goes in, it's massaged. And so I do an audit of the number of hours that have been put in and say, "Hey that doesn't make sense. I know you were away," for example, "for two of the three months, so how can you possibly have that many hours?" And so on and stuff.*

Gower also maintained a database of IP and of publications, cross-checking the reporting he received back from participants against "Scopus Alerts" which would notify him whenever a researcher involved with SERC published, or whenever 'SERC' was mentioned.

At least in SERC's case, the Australian Government's repeated attempts to streamline reporting at a policy level as a result of government-initiated reviews have not been successful at reducing the frustration of researchers. One reason for this may be that a CRC, structurally, is an uneasy melding of industry and academia. SERC's organisational charts, published each year in their Annual Report, offer a glimpse into how the passive 'organisation' was actively organised and re-organised over time in response to the reality of operational experience. In 2015 (Figure 22), the organisation was made up of the Board, under whom sat the 'C-suite' (the executive team), and then divided into five 'chunks' — the Office / Corporate division, and each of the four Research Programs. Each Research Program had a leader whose job it was to communicate decisions down to the research team, and report up directly to the executive. Between 2015 and 2016, SERC's org charts reveal a significant restructure, whereby SERC's corporate functions were divided at an executive level from research activities. Gower transitioned from a Board member to General Manager / Research Director, sitting between Greene (CEO) and the Program Leaders. The new structure gave Gower, not Greene, the responsibility of managing day-to-day operations. According to the chart, Gower sat at the junction between the two arms of SERC, but what the chart does not clearly illustrate is that almost none of the researchers working under each Research Program actually reported to Gower in an organisational sense. Instead, each researcher and program leader reported directly to their university or industry employer, and had responsibilities to that employer outside of their role with SERC. This means that Gower had responsibility for overseeing the research and ensuring it remained 'on track', but did not have any structural leverage through which to encourage reporting compliance. The simple hierarchy as depicted on organisational charts was not as reflective of the balance of power as it appears. Gower explained that this duality between how the organisation worked on paper, and how it worked in practice, was challenging.

> *… it's quite difficult from the perspective that you have … you need to manage resources that don't report to you, if that makes sense. The researchers in universities, they're line reporting straight to the Head of School, it's not to me. And so there are all sorts of techniques that one needs to use to actually get them on board and keep them delivering what they say they're going to deliver.*

Nonetheless, while the linear framework of reporting depicted in the organisational charts was, to an extent, a convenient fiction, SERC did work. Gower explained that while it was possible for him to exert "gentle pressure downwards" with the help of his relationships with researchers' line managers at their institutions, "generally you don't need to do that, it's really around just working with them". SERC operated because of, and through, a nuanced series of intentionally networked interdependencies, based on the principle that "by and large people don't want to stuff other people around, and they want to be seen to be carrying their part of the load". Gower outlined the social and organisational leverage at play:

> *… so the results that researchers are meant to deliver, so their outputs, their outputs are inputs for someone else. So it's not just me that they need to satisfy, the other team members, or other partners in the collaboration, as well. So you've got to change the narrative around, well, once you've delivered this your output will then be used to be able to do these other things … And so they become inputs for someone else.*

These unofficial, invisible social structures of obligation shifted throughout the period of SERC's operation, at times in response to SERC's official structures and restructures. Biddington explained that an ongoing issue for SERC, from a governance standpoint, had been that when SERC began, Greene was CEO of both SERC and EOS, and he also retained the position of Chair of the Research Management Committee throughout.[348] According to Biddington, Greene was placed in this 'double-hatted' situation because, at the time SERC was established, there was no person other than Greene with the qualifications and experience to fill the CEO role. This changed in December 2017, when David Ball was brought into SERC as Deputy CEO.[349] Ball's qualifications and experience in both the military and civil space technology sectors were extensive. He had been an officer with the Royal Australian Air Force (RAAF) from 1981 to 1995,[350] during which time he had worked on the MILSATCOM project (military satellite communications).[351] After leaving the Air Force he went on to work for PanAmSat and Intelsat, commercial providers of satellite services.[352] Now replaced by Ball as CEO of SERC, Greene moved to a Board position, replacing Colless. The new structure further divided SERC Corporate into Business and Finance, while Gower remained in charge of SERC's research operations as 'General Manager Research'.[353]

Throughout SERC's operation, organisational structures remained a dual function of formal delineations and informal, social networks of obligation and responsibility. Some of these formal reporting lines were depicted explicitly within SERC's own reporting, but others, such as researchers' duties to their own employers (departments or companies) were implicit, understood and enacted through the everyday interplay between individuals.

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[348] (2019). Annual Report 2018 - 2019, Space Environment Research Centre. p. 47.

[349] (2017). Annual Report 2016 - 2017, Space Environment Research Centre. p. 39.

[350] Ball, D. (2021). "David Ball." Retrieved 19/02/21, from https://www.linkedin.com/in/david-ball-08542b/.

[351] Ibid.

[352] PanAmSat was acquired by Intelsat in 2006. Amir, A. R. and S. I. Weiss. (2014). "Hughes Electronics Corporation." Retrieved 19/02/21, from https://www.britannica.com/topic/Hughes-Electronics-Corporation.; (2020). "Our Story." Retrieved 19/02/21, from https://www.intelsat.com/about-us/our-story/.; Ball, D. (2021). "David Ball." Retrieved 19/02/21, from https://www.linkedin.com/in/david-ball-08542b/.

[353] (2018). Annual Report 2017 - 2018, Space Environment Research Centre. p. 48.

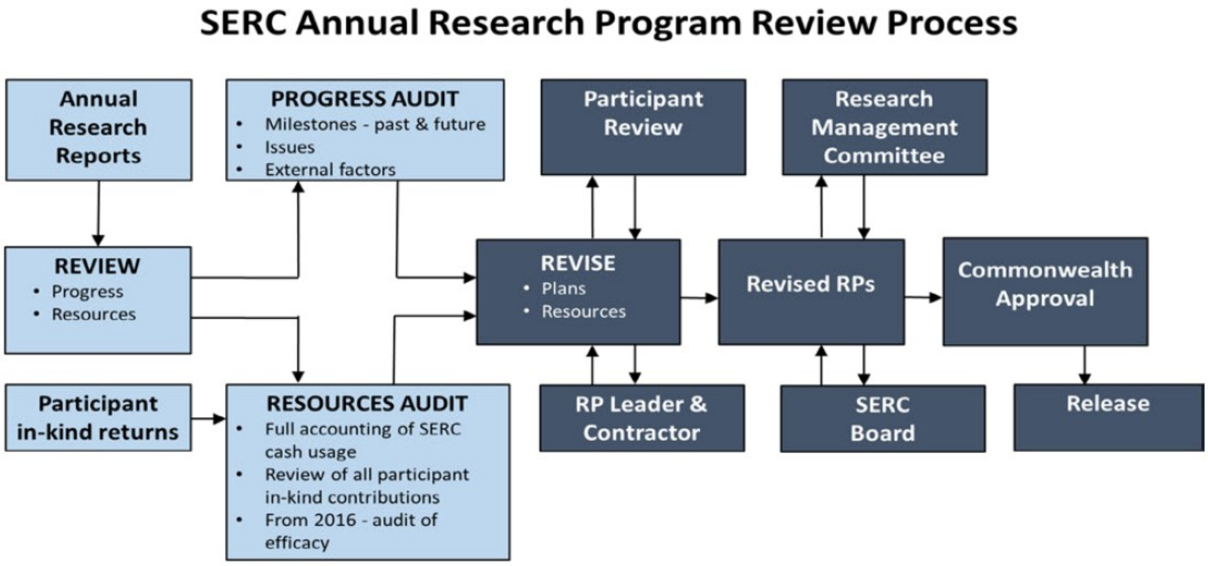

Figure 21 — Despite efforts to streamline reporting, some participants found SERC's Annual Research Program Review Process, as illustrated in their 2015 Annual Report, administratively burdensome.[354]

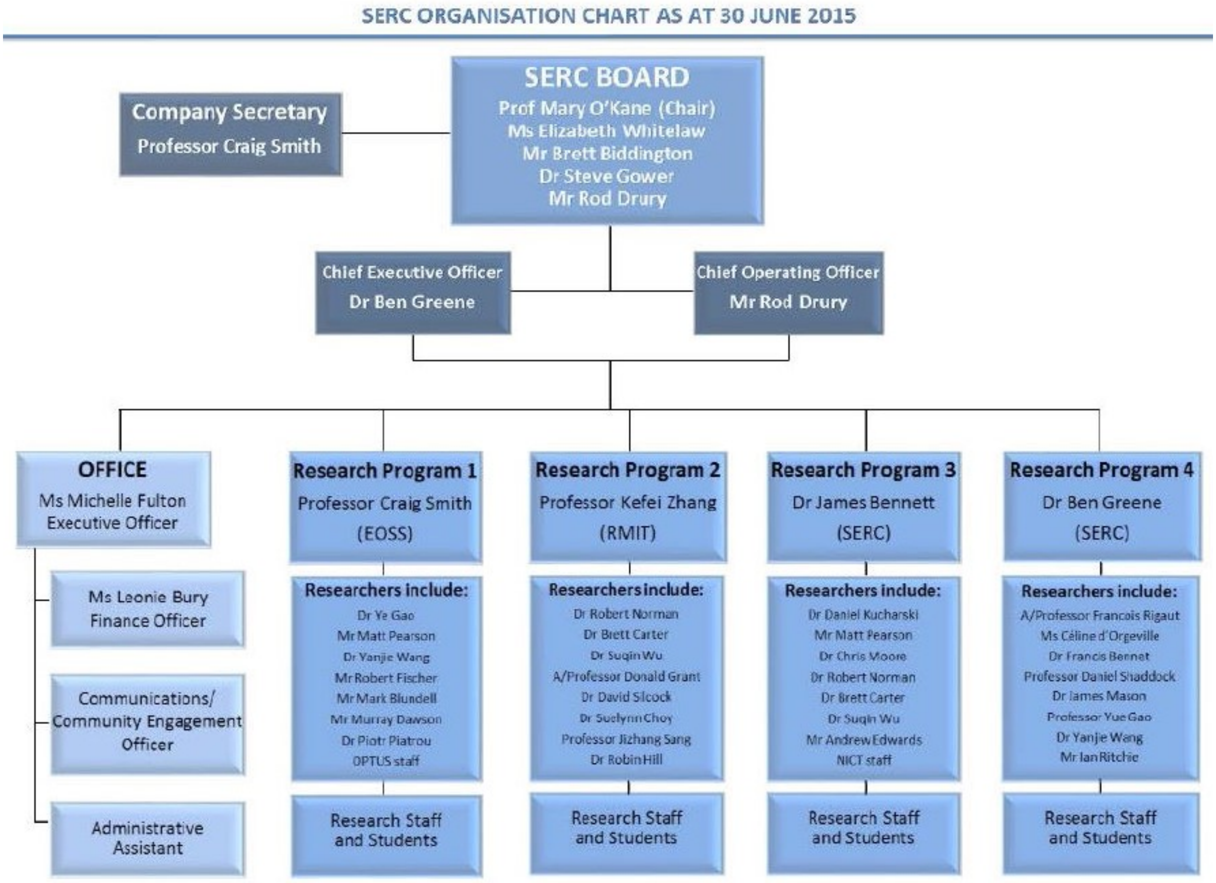

Figure 22 — At SERC's inception, each research program and the corporate function of SERC reported directly to the CEO and a COO, who in turn reported to the Board. Greene was in charge of Research Program 4.[355]

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[354] (2015). Annual Report 2014 - 2015, Space Environment Research Centre. p. 40.

[355] Ibid. p. 34.

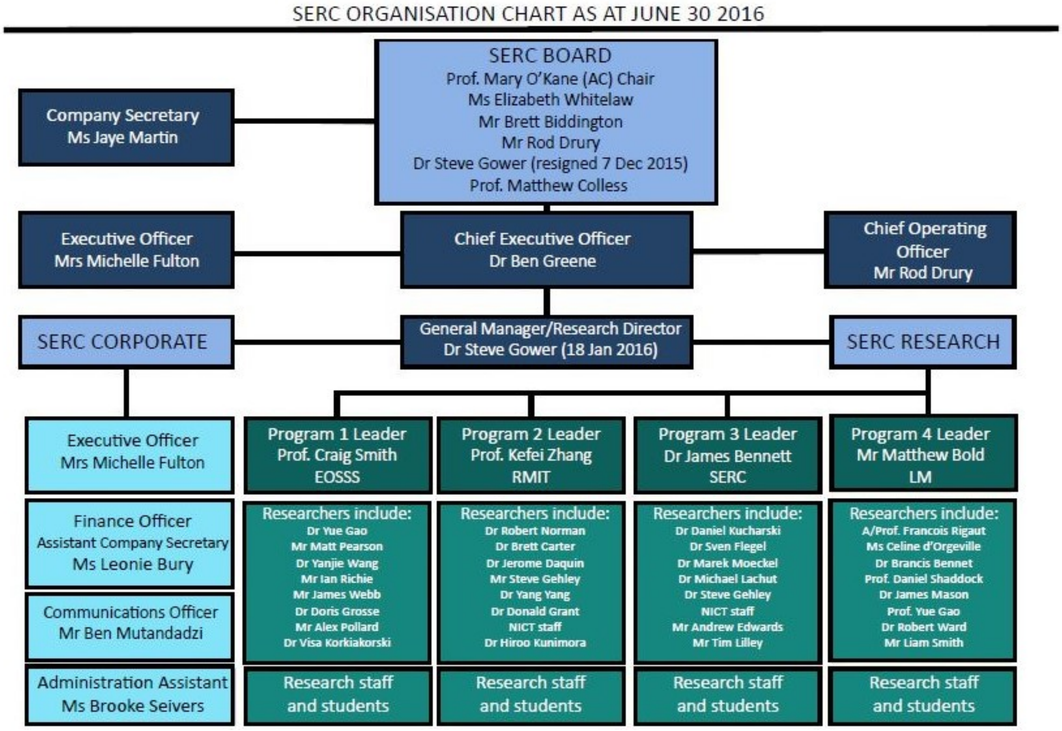

Figure 23 — SERC underwent a significant restructure in 2016 which separated the research and corporate activities of the CRC. Research Program 4 was handed over from Greene (EOS) to Bold (Lockheed Martin).[356]

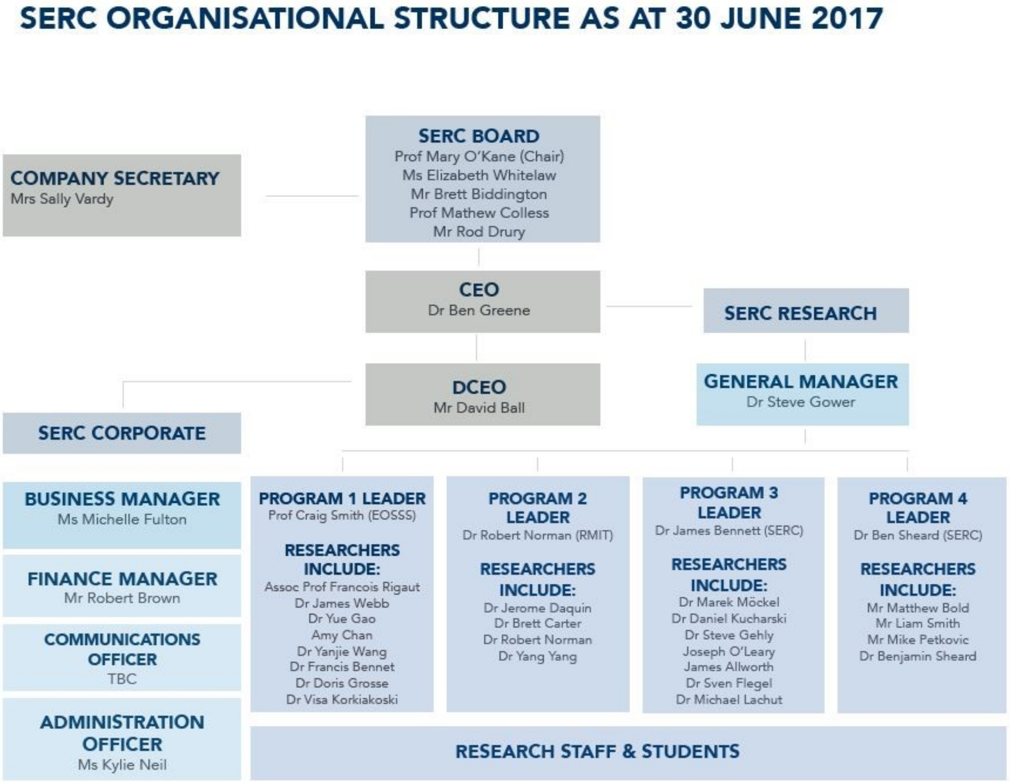

Figure 24 — By 2017, SERC had been restructured again, with Gower now responsible for research, and Ball (Deputy CEO) taking on the corporate side. Greene remained SERC CEO. Research Program 4 was now run by Sheard (SERC).[357]

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[356] (2016). Annual Report 2015 - 2016, Space Environment Research Centre. p. 51.

[357] (2017). Annual Report 2016 - 2017, Space Environment Research Centre. p. 44.

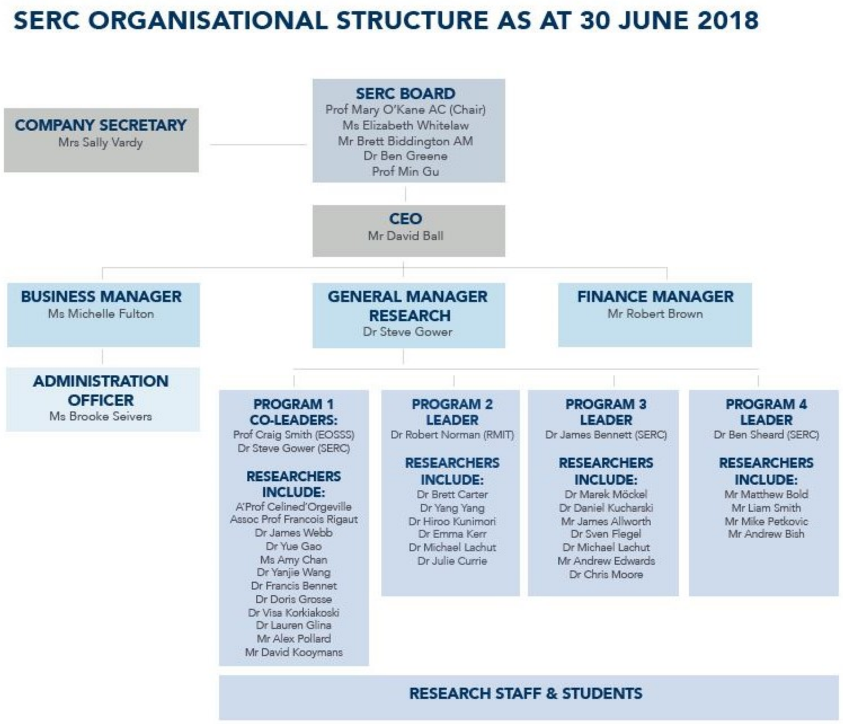

Figure 25 — In December 2017, Ball replaced Greene as CEO. A further delineation was made by splitting 'Corporate' into 'Business' and 'Finance'. Colless left the Board, replaced by Greene. Gower joined Smith to co-lead Research Program 1.[358]

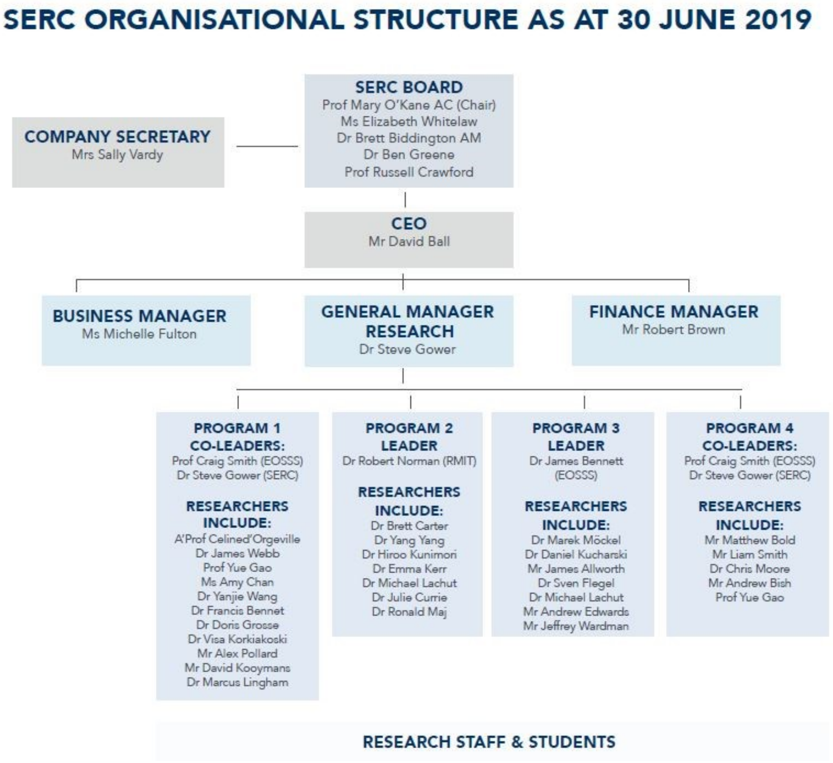

Figure 26 — The main change from 2018 to 2019 was that Smith and Gower took over running Research Program 4. Otherwise SERC's formal structure remained relatively static.[359]

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[358] (2018). Annual Report 2017 - 2018, Space Environment Research Centre. p. 48.

[359] (2019). Annual Report 2018 - 2019, Space Environment Research Centre. p. 52.

4.2.3 SERC’s financial structure

SERC’s financial structure was complicated, but it is its complexity that makes it worthy of proper, detailed description. In many ways it was the arrangement and flow of money, real and imaginary, that made SERC an entity in a way that is quite distinct from PILOT, the contested signifier of ideas. Opinions may have differed on SERC’s purpose and achievements, but financial analysis grounds that discussion by establishing clear and universal stakes. ‘Success’ is hazy, but ‘value’, however contested it is along the way, is measurable at the moment it is accounted. Moreover, and of significance for this research, it is possible to gain a clearer understanding as to how a system *actually* operates by looking in particular at the way that individuals encounter, understand, and navigate its opaque and complex aspects. In this section I offer a detailed analysis of SERC’s publicly available accounts, which provides a ‘top-down’ view. I juxtapose against this analysis the descriptions research participants provided for me of how they interacted with SERC’s financial processes on a day-to-day basis, offering a complementary ‘bottom-up’ view. By thus laying out a detailed picture of SERC’s financial structure as it was reported and as it was experienced, I provide an empirical description of one embodiment of a private-public partnership in the Australian space sciences sector. Arguably, without such detailed descriptions of how money flows in specific cases, policy or funding discussions about the Australian space industry rely on partial, and partially selected information only.

Like SERC’s organisational structure, the funding mechanisms that underpinned the CRC’s activities were disparate. For a start, SERC was funded through a mix of cash contributions (from the Australian Government) and in-kind contributions (from the partner organisations and research institutions). ‘In-kind’ refers to the provision of personnel, equipment, or facilities, the value of which was considered part of the funding contribution from that institution. Tracking down the accounts for CRCs can be difficult, and piecing together an accurate financial picture from the sources available is equally challenging. In SERC’s case, as a registered charity, the organisation was required to lodge financial reports annually with the Australian Charities and Not-for-profits Commission (ACNC), and until 2018 SERC also included basic financial reporting in its Annual Reports. I used both of these sources in my analysis. SERC’s Annual Reports are still easily located, but following its official deregistration in mid-2021, the financial records lodged with ACNC are no longer publicly available.[360] Perspectives on how much funding was received, and from whom, differs depending on the source (even among SERC’s own participants). In summary, based on my analysis of information that was publicly available at the time, SERC received approximately $60 million from 2015-2020, which comprised approximately $20 million of Commonwealth funding, and approximately $40 million in in-kind contributions from participants.

To take a more granular approach, SERC’s initial grant from the Australian Government was reported in published government records as being $19.83 million between 2014-2019.[361] According to the 2015 Financial Report submitted to the ACNC, the Commonwealth Agreement governing SERC

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[360] Annual Reports are available at (2021). "About the Space Environment Management CRC." Retrieved 29/09/2021, from https://www.serc.org.au/about. Financial Reports were previously publicly available at (2021). "Space Environment Research Centre Limited (ABN: 70169043467)." Search the ACNC Charity Register Retrieved 29/09/2021, from https://www.acnc.gov.au/charity/9d89fc9ef62c51a0b50a0c8c9b26ec0e#financials-documents. SERC’s formal application for Voluntary Deregistration is available via (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).

[361] (2020). CRCs Over Time. Cooperative Research Centres (CRC) Program. Australian Government Department of Industry, Science, Energy and Resources. p. 14.

specified that it would receive $23 million in cash contributions from the Commonwealth and participants from 2014-2019.[362] These figures align roughly with the actuals reported in the notes to the 2020 Financial Report, which came to approximately $21.7 million.[363] In-kind contributions were calculated and added on top of this cash amount to form the total budget for the CRC. According to the notes to the annual income statements reported in the Financial Reports lodged with the ACNC, in-kind contributions came to approximately $38.5 million.[364] Adding these amounts together, and also including other revenue and interest that appears on the Financial Reports, leads to a total revenue amount of almost $59 million from 2015 to 2020.[365]

But according to other sources, SERC's funding was up to more than twice as much as the ~$60 million recorded in financial filings. In our conversations, Gower said that the funding added to "about $90 million in total, when you look at cash and in-kind. Between 60 and 90. It was 60, but we've gone a little bit longer, so we've managed to get a little bit more teed up". Bennet, on the other hand, said that "the total budget was $120 million. I think the actual government contribution was $50 million — maybe it was 35. I don't know, something like that". At the top end of all

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[362] (2015). Financial Report for the period 10 April 2014 to 30 June 2014. CRC for Space Environment Management managed by the Space Environment Research Centre Limited (SERC). Australian Charities and Not-for-profits Commission (Note 15) p. 19.

[363] (2020). Financial Report for the period 1 July 2019 to 30 June 2020. CRC for Space Environment Management managed by the Space Environment Research Centre Limited (SERC). Australian Charities and Not-for-profits Commission p. 22.

[364] (2015). Financial Report for the period 10 April 2014 to 30 June 2014. CRC for Space Environment Management managed by the Space Environment Research Centre Limited (SERC). Australian Charities and Not-for-profits Commission (Note 3) p. 17.; (2016). Financial Report for the period 1 July 2015 to 30 June 2016. CRC for Space Environment Management managed by the Space Environment Research Centre Limited (SERC). Australian Charities and Not-for-profits Commission (Note 3) p. 18.; (2017). Financial Report for the period 1 July 2016 to 30 June 2017. CRC for Space Environment Management managed by the Space Environment Research Centre Limited (SERC). Australian Charities and Not-for-profits Commission (Note 3) p. 17.; (2018). Financial Report for the period 1 July 2017 to 30 June 2018. CRC for Space Environment Management managed by the Space Environment Research Centre Limited (SERC). Australian Charities and Not-for-profits Commission (Note 3) p. 17.; (2019). Financial Report for the period 1 July 2018 to 30 June 2019. CRC for Space Environment Management managed by the Space Environment Research Centre Limited (SERC). Australian Charities and Not-for-profits Commission (Note 3) p. 18.; (2020). Financial Report for the period 1 July 2019 to 30 June 2020. CRC for Space Environment Management managed by the Space Environment Research Centre Limited (SERC). Australian Charities and Not-for-profits Commission (Note 3) p. 19.

[365] (2015). Financial Report for the period 10 April 2014 to 30 June 2014. CRC for Space Environment Management managed by the Space Environment Research Centre Limited (SERC). Australian Charities and Not-for-profits Commission (Statement of Comprehensive Income) p. 10.; (2016). Financial Report for the period 1 July 2015 to 30 June 2016. CRC for Space Environment Management managed by the Space Environment Research Centre Limited (SERC). Australian Charities and Not-for-profits Commission (Statement of Comprehensive Income) p. 9.; (2017). Financial Report for the period 1 July 2016 to 30 June 2017. CRC for Space Environment Management managed by the Space Environment Research Centre Limited (SERC). Australian Charities and Not-for-profits Commission (Statement of Comprehensive Income) p. 9.; (2018). Financial Report for the period 1 July 2017 to 30 June 2018. CRC for Space Environment Management managed by the Space Environment Research Centre Limited (SERC). Australian Charities and Not-for-profits Commission (Statement of Comprehensive Income) p. 9.; (2019). Financial Report for the period 1 July 2018 to 30 June 2019. CRC for Space Environment Management managed by the Space Environment Research Centre Limited (SERC). Australian Charities and Not-for-profits Commission (Statement of Comprehensive Income) p. 10.; (2020). Financial Report for the period 1 July 2019 to 30 June 2020. CRC for Space Environment Management managed by the Space Environment Research Centre Limited (SERC). Australian Charities and Not-for-profits Commission (Statement of Comprehensive Income) p. 10.

estimates, an Australian Broadcasting Corporation article in 2014 reported that SERC was a "new $150 million Australian research centre".[366]

The simplest explanation for such a disparity between the accounts and the perceptions of researchers and the media is that CRC accounting is complicated. In addition to cash funding coming in from numerous sources, the use of equipment, personnel and services also has a value that needs to be accounted for in some way. Assessing the value of such so-called 'in-kind' contributions is an imprecise art, a fact admitted openly in the inaugural 2015 Financial Report which states that "there is an element of estimation and judgement to the value of in-kind contributions".[367]

The first step of in-kind calculations, the personnel contributions, were difficult to measure. Each partner allocated some of their employees to SERC activities, but each employee was not necessarily expected to spend 100% of their time on SERC projects. As an accounting method, SERC decided to use a Full Time Equivalent (FTE) measure.[368] Rather than try to cost each person's time based on what they were actually being paid by their employer, SERC instead opted to group everyone into one of four categories, each of which had an agreed dollar value to cover their salary and overheads. The highest category, Category 1 ("Program Leader, Senior Manager") was worth $420,000 per annum.[369] A "Key Researcher / Manager / Project / Theme Leader" cost $280,000, a "Researcher / Professional" was $220,000 and Category 4, "Other (support staff — technical, administrative etc.), was valued at $180,000.[370]

In theory, this system is simple and clean, but in practice, difficulties arose for several reasons. Gower explained that the most basic issue was that each of the partner organisations had a different definition of what constituted a Full Time Equivalent (FTE) loading. SERC's Japanese partner, NICT, considers one FTE to be "45 hours a week of one person on the tools", while USA partners operated on a 40-hour standard week. For SERC's Australian industry partners, on the other hand, an FTE was officially 38 hours per week, but with varying overtime conditions depending on the organisation. Gower found that the maths became even more complicated when it came to university partners, because most of the SERC staff contributed from academic institutions had teaching and research obligations, and could only spend 22 hours of their 35-hour working week on SERC. The official SERC position was that that "actual time" recorded on SERC project work "requires a certain level of estimate and judgement by project leaders", taking into account project budgets and agreements.[371] In practice, the enactment of this principle of "judgement" was open to dispute from all sides, not least because project leaders were, according to the explanation given in the financial reports, required to exercise judgement as to their own "total value" as well as that of their team members.[372] Gower went on to explain that he felt that the system itself was flawed because it incentivised overestimation of hours ("value") contributed. He felt strongly that "you've got to engage with universities on commercial terms", and that payment on delivery would be a better approach to "actually get out what you need".

> *… when I've been in discussion with the Department of Industry, I said "you cannot use FTE, you need to define what an FTE is, how many hours." Because it's open to abuse. And*

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[366] Smith, C. and C. Kimball (2014). New Australian Research Centre to Remove Space Junk, Save Satellites and Spacecraft. ABC News, ABC.

[367] (2015). Financial Report for the period 10 April 2014 to 30 June 2014. CRC for Space Environment Management managed by the Space Environment Research Centre Limited (SERC). Australian Charities and Not-for-profits Commission p. 16.

[368] Ibid. p. 13.

[369] Ibid. p. 13.

[370] Ibid. p. 13.

[371] Ibid. p. 13.

[372] Ibid. p. 13.

> *universities are full of lots of very smart people, who are used to gaming systems. And that's what they do to get their funding. So you put a system in place, and they will game it.*

In addition to human in-kind, each participant also contributed non-personnel in-kind (for example, specialist equipment), for which monetary calculations were determined in accordance with the valuation principles in the Participants Agreements.[373] Such principles include commercial rental estimates (buildings), replacement cost (equipment), and cost of operation (office and laboratories).[374] Where valuation principles could not be applied "a Director's valuation is used".[375] I was unable to ascertain precisely how and when the process of using a Director's valuation was used, and whether the Board had ultimate oversight. However, what was clear was that, as Gower put it, "not all in-kind is created equally", and partners were financially incentivised to try to get as many contributions as possible recognised at the highest value they could. The Research Management Committee, chaired by Greene, was given responsibility for assessing the "quality and quantity of in-kind", and ensuring that valuations provided were reasonable.[376]

For example, EOS provided the use of the EOS Space Research Centre to SERC, which was their major in-kind contribution aside from personnel.[377] According to the 2015 Financial Report lodged with the ACNC, the value of this contribution was estimated at $13,516 per day, and was annualised to $4.9m per annum (equivalent to $13,516 multiplied by 365 days).[378] The accounting assumes that SERC will use 39.18% of this total 365 day allocation, worth $1.9 million per annum, or the equivalent of 143 total days of usage in a year. By contrast, ANU estimated that SERC would use 100% of the lab and office space at Mount Stromlo, and estimated the value at $626 per square metre, adding up to $313,000 per annum. Unfortunately for my research efforts, SERC ceased reporting in-kind estimates or actual usage after 2015, only reporting those in-kind shortfalls which were "more than 10% less than the contracted amount as set out in the Commonwealth Agreement".[379] Without access to these reports or to the Commonwealth Agreements it is impossible to determine to what extent estimates were exceeded over the time SERC operated. But as Gower noted, the fact he thought that ANU's internal valuation for their lab and office space was "way above market rates" was immaterial: "you've just got to wear that, there's nothing you can do about it. If you want to be located there, that's the way it works".

Gower's job of balancing budgets and ensuring compliance with Commonwealth Agreements no doubt influenced his perspective on the issue, and general consensus among those I spoke to from SERC's research side was that Gower had a difficult job. At the same time, the lack of transparency that hampered my efforts carrying out this research also frustrated SERC's research staff. They encountered difficulties due to what they saw as a lack of clear communication from management to those working on the technical problems as to the precise parameters of the budgetary environment in which they operated. Travouillon, for example, described to me how the SERC administration, which focused mainly on financial management at the time he was with the CRC,

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[373] Ibid. p. 13.

[374] Ibid. p. 13.

[375] Ibid. p. 13.

[376] Gower, S. (2020). Research Interview. HREC 2020/145. A. Handmer.

[377] (2015). Financial Report for the period 10 April 2014 to 30 June 2014. CRC for Space Environment Management managed by the Space Environment Research Centre Limited (SERC). Australian Charities and Not-for-profits Commission p. 14.

[378] Ibid. p. 14.

[379] (2016). Financial Report for the period 1 July 2015 to 30 June 2016. CRC for Space Environment Management managed by the Space Environment Research Centre Limited (SERC). Australian Charities and Not-for-profits Commission p. 13.

“kind of made things more opaque”. In reaction to this muddy fiscal environment, some research staff just ignored financial matters altogether. To Bennet, for example, the in-kind contributions, in whatever form they were or were not reported in the financial or annual reporting process, constituted imaginary money, irrelevant to day-to-day operations.

> *… partner contributions, so in-kind contributions, lab space, equipment that already existed, that kind of stuff … So that money didn’t really exist. It did for some of the FTE, which went into SERC. In terms of the actual budget, which we saw — we actually never saw a budget — the budget was split into each of the four research programs.*

What *did* matter for research operations was how much cash was available to purchase equipment and technology. Bennet described SERC’s “specific administrative structure” as “almost like a black hole”. He explained that the team “never knew how much money was left. We never knew how much money we had to play with, or to work with”. Frustrated with official processes, the team would go around them to speak to the individuals working in the business office.

> *… we would say “okay, we need a few hundred thousand dollars to do this” and we wouldn’t hear anything back, and so we would go there and say, “can we do that?” And they’d say, “oh yeah, I remember seeing that allocated in the budget”. And we’d think, “okay, well what does that mean? Can we buy the stuff?” And it kind of depended day-to-day, as to who you asked, as to whether it was allocated or not.*

Alongside complications arising from procurement requests, individuals from one partner organisation were frequently unaware of purchase requests or actual expenditure, completed or intended, by other organisations within the CRC. This had the effect of making the process of distributing SERC’s assets, in Bennet’s words, “a little bit nebulous”. But at the same time, Bennet acknowledged that in some cases SERC’s financial system turned out to be easier to navigate than ANU’s own internal procedures. Over time, the ANU team found the path of least resistance and figured out how to efficiently use SERC to circumvent problems with the university’s procurement systems.

> *… there were problems with the way the financing works, at ANU, interacting with SERC because, ANU procedures take so long. Sometimes it would take a year and a half for SERC to get invoiced, for something we’d bought. And that’s just, not okay. You know? And … That just came down to the way that central ANU finances work. Really slowly. So by the end of SERC, we sort of managed to get that into a reasonable state, by just telling SERC what we needed to buy. And then they went and bought it, and then gave it to us.*

Thus, although Bennet felt that the cooperative element of the CRC was hampered by the lack of visibility (because it meant that he was not able to plan and solve problems in the most efficient way), “at the end of the day, we ended up buying pretty much everything we needed”.

Another core element to the financial structure which was explicitly excluded from in-kind or cash accounting was Intellectual Property (IP).[380] IP had (and has) value which needed to be assessed, recorded, balanced against other factors (the official Agreements each partner signed at the commencement of SERC linked IP rights to cash and in-kind contributions and voting rights) and ultimately allocated to partners. The process SERC developed to “transparently assess the actual,

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[380] (2015). Financial Report for the period 10 April 2014 to 30 June 2014. CRC for Space Environment Management managed by the Space Environment Research Centre Limited (SERC). Australian Charities and Not-for-profits Commission p. 13.

aggregate contributions of members to each research project to allow equitable allocation, among members, of rights to IP" involved establishing boundaries between the background IP (IP which partners brought to the project) and the new IP which was formed through SERC's activities.[381] SERC also committed to establishing IP 'roadmaps', against which project leaders would be required to report progress, and to control publication of research arising from SERC's activities "to ensure IP protection is not degraded".[382]

Over time, SERC developed practical measures for managing IP at an operational level. The 2016 Annual Report, for example, describes initiatives including 'IP Awareness and Training'. In addition to the planned regular reporting process by project leaders, measures included "numbered lab notebooks" which were "issued to all SERC researchers and students",[383] and vetting and approval process through which any form of research was checked for "unintentional disclosure of Centre IP" prior to publication.[384] In practical terms, Samantha Le May, one of SERC's scholarship recipients, explained that "they need to approve, that it is basically okay for me to talk about my research at conferences", and that there was a "process" for doing so.[385]

The 2015 Annual Report envisaged that IP would eventually be distributed through purchase of "licence fees" for IP, which would be operated on an 'arm's length' basis.[386] SERC's member organisations would have "no exclusive or preferred right to any SERC IP, but must bid for IP licences on the same terms as non-members".[387] However, despite a mention of "commercial discussions regarding IP related to methods for measuring atmospheric turbulence and laser light generation at sodium wavelengths" in the 2017 Annual Report,[388] at no point did any annual report disclose that any IP had actually been "sold, transferred or licensed for commercialisation during the reporting period".[389] All IP distribution was left until the end of SERC's existence, after the publication of the final Annual Report in 2019. The most recent financial report, from 2020, stated that "SERC will arrange for all project IP and research assets to be assigned to the corresponding project Participants. As such, it will have no IP or research assets from its operations".[390] Unfortunately for the purposes of my research, the report did not provide further detail on this process.

In this section I have provided an overview of how value (cash, in-kind and IP) was exchanged during SERC's operation. As a CRC, SERC's financial setup was important in that it allowed industry and academia to collaborate under a single overarching structure that was purpose-built for the task. My analysis has also shown that there was an operationally important divergence between the streamlined way that SERC reported its financial status, and the way that individuals within SERC navigated such processes in day-to-day practice.

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[381] (2015). Annual Report 2014 - 2015, Space Environment Research Centre. p. 23.

[382] Ibid. p. 23.

[383] (2016). Annual Report 2015 - 2016, Space Environment Research Centre. p. 39.

[384] Ibid. p. 39.

[385] May, S. L. (2020). Research Interview. HREC 2020/145. A. Handmer.

[386] (2015). Annual Report 2014 - 2015, Space Environment Research Centre. p. 23.

[387] Ibid. p. 23.

[388] (2017). Annual Report 2016 - 2017, Space Environment Research Centre. p. 35.

[389] (2015). Annual Report 2014 - 2015, Space Environment Research Centre. p. 23.; (2016). Annual Report 2015 - 2016, Space Environment Research Centre. p. 39.; (2017). Annual Report 2016 - 2017, Space Environment Research Centre. p. 35.; (2018). Annual Report 2017 - 2018, Space Environment Research Centre. p. 38.; (2019). Annual Report 2018 - 2019, Space Environment Research Centre. p. 42.

[390] (2020). Financial Report for the period 1 July 2019 to 30 June 2020. CRC for Space Environment Management managed by the Space Environment Research Centre Limited (SERC). Australian Charities and Not-for-profits Commission p. 2.

4.2.4 SERC’s social structure: the construction of the SERC family

SERC was not just a CRC, a company, or a financial structure; it was, importantly, a social organisation of individuals who came to work together not just because they had to, but because they wanted to. Working within, and at times against, the complex financial and organisation structures of SERC were a group of individuals, ranging from PhD students to board members, each with their own expertise, perspective, and style of working. In this section I focus on the experiences of early career researchers who worked at SERC to draw out some of the diverse reasons that individuals are drawn to the space sector, and how these particular researchers saw themselves and where they fit within an organisation of other individuals. Their understanding of what it was that they were at SERC to do and of SERC’s overall purpose is also important context for Chapter 6, which will more explicitly address issues of moral responsibility. A theme that emerged consistently in my interviews with the more junior members of SERC, particularly those students who did their postgraduate projects through the CRC, was the idea of the SERC ‘family’. While many of those working in the CRC were physically present at Mt Stromlo throughout, others were based in other states, and for these students especially, the sense of community was something they valued highly.

Samantha Le May was in her final year of her undergraduate degree in Environmental Science at RMIT when she started attending research seminars at the university’s Satellite Positioning for Atmosphere, Climate and Environment (SPACE) Research Centre. The centre “focuses on the development of Platform Technologies for Space, Atmosphere and Climate”.[391] The director of the SPACE Research Centre was Professor Kefei Zhang,[392] who was the leader of SERC Research Program 2 from SERC’s inception until July 2016.[393] At the time, Le May was interested in analytical chemistry, and approached the SPACE Research Centre to discuss doing an Honours project “using satellite data for weather prediction, essentially. Or atmospheric profiling”. She wanted to use satellite data to do atmospheric chemistry, but when she started attending the seminars run by SPACE she encountered discussions on space debris, something she had “no idea about, before that point in time”.

Le May was fascinated by space debris, which she saw as equivalent to “leaving rubbish up there”. Although she acknowledged that “classically we think of ‘environment’ as being something that is ‘living’”, she saw space debris as an environmental, “human impact”, and “sustainability” issue. Her interest in the “big picture” of the space environment extended beyond the sustainability of satellites used to “track things like bushfires, or measure groundwater reserves” to viewing space as a resource “needing protection, for the benefit of the whole of Earth, rather than just one region being able to take advantage of it, as well as future generations”. She explained:

> *… we have to have a lot of emerging space economies, and I think, if … those who have a lot more space activity, compared to those who have a lot less space activity, go forth and kind of … you know technology moves a lot quicker than what, potentially policy and regulation does, so … I think if we sort of, continue in this whole “oh it’s the wild west, and I do what I want” approach to developing in space … I think it’s great to encourage innovation, but I think if we are not doing it in a way that is considering the needs of future generations, and I think that’s really, it’s unfortunate and also, there is a lot of parallels there right, with traditional environmental problems.*

Zhang invited Le May to attend an intensive course in Canberra on orbit determination and adaptive optics, which was attended by the ‘first wave’ of SERC students and was taught by Bennet and

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[391] (2018). "Satellite Positioning for Atmosphere, Climate and Environment." Centres and Collaborations Retrieved 24/02/2021, from https://www.rmit.edu.au/research/centres-collaborations/space-research-centre.
[392] (2016). Annual Report 2015 - 2016, Space Environment Research Centre. p. 14.
[393] (2017). Annual Report 2016 - 2017, Space Environment Research Centre. p. 22.

Rigaut. Despite not understanding all the content, Le May "very much became motivated by the fact that this was an important area of research", and "pestered them to support me on an honours project". During the course, she met the industry participants, including then-CEO Greene and others from Optus and EOS Space Systems — "that's where I started meeting the 'SERC family'".

SERC funded Le May to do an undergraduate Honours research project modelling the evolution of space debris, in which she attempted to find the number of satellites that could be in orbit before the "tipping point" of Kessler syndrome is reached. Unsatisfied with the European Space Agency model 'MASTER', Le May "became obsessed" with the question of how to build a "better" model, which brought together technical and policy considerations. Following her Honours research, SERC funded Le May with a 'top up' scholarship to do a PhD project focused on developing a database connecting technical information on space situational awareness with policy and regulatory data.[394] She found that many of SERC's research partners were developing orbit determination models that relied on inaccurate assumptions about the nature of the spacecraft they were tracking. Le May hoped that by "drawing together pieces of information", assumptions could be reduced, and "informed by a useful piece of information". In addition, Le May was interested in "trying to understand how space debris mitigation policies were set, and what science was informing the policies", with a focus on creating better tools to assist with compliance measures.

> *… what's the point in having policies if we don't have a way of keeping track of people complying towards those policies, as well. How do we move into a sphere where we can start measuring things like compliance, and that sort of thing? So, my project, even though it isn't based on actually being able to measure compliance, so it doesn't have an outcome that's like, "oh, now we can measure compliance", it's just really pulling these, sort of, diverse types of information together and presenting this as an option that, you know, if we do start connecting these information types, and actually making that accessible for use in research, then we can ask some really interesting questions and it could be used as a tool in these different areas.*

Also present at the orbit determination and adaptive optics "crash course" was Jesse Cranney, a PhD student from the University of Newcastle who joined SERC to work on a project on predictive control for adaptive optics.[395] Cranney had not originally planned to do a PhD after finishing his Honours project: "I had this job in industry lined up working on electrical stuff, and I thought "Yep I'm going to take that". You know, good money, and I get to be in Newcastle".

> *And then my supervisor said "would you be interested in doing a PhD? There's this SERC scholarship thing, so you can get the top up scholarship and you get to work on satellite tracking and telescopes, and stuff". And, I kind of … Initially I said, I'm more keen to just get in and make money, and, you know, be based at home … And then, I thought about it a while longer, and I eventually convinced myself, that I wouldn't be able to live with myself, if I kind of didn't take this opportunity to do something fun and space related. You know, I knew I'd be regretting it in the future. So, for 10-year-old me's sake, I said yes.*

Cranney remained based in Newcastle, travelling to Mt Stromlo to work with co-supervisor Francois Rigaut and touch base with the team every few months. Like Le May, he found the annual SERC

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[394] In the Australian tertiary system, the federal government provides a base stipend to students doing PhD studies by research (Research Training Program – RTP) at certain universities, and students can then seek out 'top up' opportunities such as that offered by SERC. See (2020). "Research Training Program." Research Block Grants Retrieved 25/02/2020, from https://www.dese.gov.au/research-block-grants/research-training-program.

[395] Cranney, J. (2020). Research Interview. HREC 2020/145. A. Handmer.

Colloquium, an initiative Gower had started, a useful experience, using the opportunity to "catch up with everyone". Gower felt that likewise, for the management team, the colloquium was an important opportunity to establish a narrative for participants that situated their individual research activities within a "tapestry" which established broader context and organisational mission, as well as "where each person's expertise actually fed into that picture".[396]

The colloquium was particularly important to participants who were based interstate, because it enabled them to connect in person with the team. Like Le May and Cranney, Joseph 'Joe' O'Leary, another SERC PhD student, was based interstate, at the University of South Australia, doing a PhD in applied mathematics.[397] He was working on research problems that were peripheral to the technical instrumentation work being done on Mount Stromlo, but nonetheless felt a strong sense of community. In our formal interview, O'Leary told me how he had initially intended to research the effects of relativity on space-based clocks.

> *… the idea was that there are some effects on space clocks, which are due to the theory of relativity. That is, clocks that are moving relative to some inertial body will become dilated. And also in different gravity wells — I mean, in varying gravity fields, there is also effects on the clocks. But there's lots of effects that are really small, that happened due to maybe the fact that the orbit is not circular, it's elliptical. So some parts of it, it has different effects, on the orbit. Due to the rotation of the earth, the signals might be getting dilated. So we were going to look into these more specialised effects, of the space-based clocks.*

But after just a month of working on clocks, O'Leary decided that SERC "had a much more interesting topic, basically". With SERC, O'Leary started working on orbit determination and orbit propagation with Research Project 3, "just looking at the basic mechanics of objects which orbit the earth". His interest was in finding more accurate ways of describing, and thereby predicting, the movements of objects in orbit. O'Leary explained that the way relativity is currently accounted for in these calculations is "technically wrong".

> *… it works, but it doesn't work, if you know what I mean? Just because something works, doesn't mean it's correct. There is a much more fundamental way of approaching it, and I guess I was really looking at just the basic way of how you go about that.*

Despite working on a mathematical problem that did not require co-location, O'Leary visited Mt Stromlo "quite a few" times, meeting with other researchers to narrow the scope of his work (which he described as being initially "a bit loosey-goosey"), and learn more about the needs and interests of SERC's other research partners. During visits to SERC and to Optus Satellite headquarters in Sydney "just to see how everything fits in, what sort of research is needed" O'Leary developed "a friendship and acquaintance" with James Bennett, the Leader of Research Program 3, who went on to work for EOS.[398] Bennett was also a mathematician, and became the co-supervisor of O'Leary's thesis, which O'Leary described as "a good fit for all of us".

Like Le May, O'Leary found that the social side of the SERC organisation was "kind of like a family". For O'Leary, the social cohesion was a product of like-mindedness and age: he felt that "because

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[396] My research suggested that this specific goal was not achieved in practice (see Chapter 6). For more on SERC's research opportunities see (2021). "Case Study: New Knowledge, Products or Processes." Retrieved 21/09/21, from https://www.serc.org.au/influencing-uptake-new-knowledge-case-study.

[397] O'Leary, J. (2020). Research Interview. HREC 2020/145. A. Handmer.

[398] Bennett, J. (2021). "James Bennett." Retrieved 14/05/2021, from https://www.linkedin.com/in/james-bennett-754470b9/.

most of the people were very young, it was easy for everybody to, I guess, gel. You know, go for dinner".

> *I mean, even senior people, like for example … Well I don't want to keep mentioning James [Bennett]. But James is quite young. The PhDs, well I don't really recall any overly mature aged PhDs. But yeah, we were all similar ages, similar interests, we were all obviously interested in maths and engineering, how objects fly around the earth and stuff like that. So yeah, I thought it was very social, maybe too social actually for some aspects. But yeah, it was great!*

For those visiting or permanently based at Mt Stromlo, SERC also held a barbecue for all participants every second Friday. Like O'Leary, Cranney found the senior management team at SERC "super friendly", relating how Gower and Michelle Fulton (SERC's business manager) would "love to have a chat at lunch". Le May recalled that "we did a silly Secret Santa. And there's Nerf guns in the office and stuff too. So, that was fun".

In this chapter I have analysed SERC through multiple structural lenses to demonstrate the organisational boundaries within which individuals and groups operated. By juxtaposing publicly available information with first-hand interview-based research, I have shown how SERC became the overarching entity within which institutions and individuals pursued disparate goals. I then traced in detail how SERC's research and organisational structure facilitated the aims of its partner-organisations while fulfilling its research, program, and corporate governance requirements. With this organisational backdrop assembled, I provided a brief account of SERC's financial structure, giving context for the public-facing accounts by outlining how value (cash, in-kind and IP) was negotiated, decided, and allocated. Finally, I compiled perspectives of early career researchers who worked at SERC to offer a complementary picture of a densely networked community that, while not explicitly referenced in SERC's formal reporting processes, was an important part of its structure and operations.

Figure 27 — An example of an internal SERC Christmas email, provided by Gower.[399]

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[399] Gower, S. (2019). Have a Happy and Safe Festive Season. SERCular Newsletter (Materials provided by Gower for my research, HREC 2020/145), Space Environment Research Centre (SERC).

Chapter 5: The SERC experiment — legal and technological elements

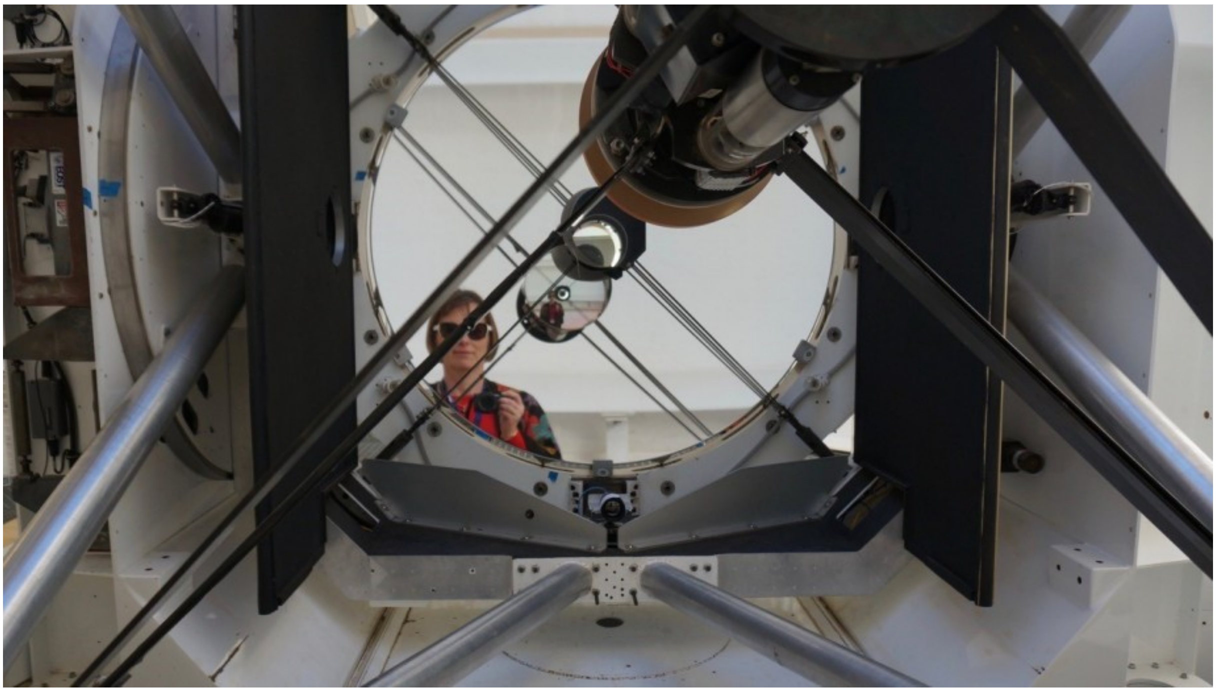

Figure 28 — SERC / ANU instrument scientist Celine d'Orgeville with the EOS 1.8-metre telescope.[400]

As an organisation then, SERC functioned, operating both in spite of and because of its complicated networks of structures, financial processes, and personal relationships. After its rapid creation in late 2014, work began in earnest on SERC's research and technical outputs. The laser-ablation technology that those working with SERC hoped to develop was a form of 'Active Debris Removal', known by the acronym ADR. Over the last decade, numerous technological solutions for conducting ADR have been proposed. At the time SERC was operating, alternatives to lasers under consideration internationally included tentacles, robotic arms, nets, tethers, harpoons, lassos, foam, and adhesives.[401] 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.[402] ADR is incredibly technically complicated, whether attempted from space or from Earth. In what follows, I touch upon the precise technological challenges which the SERC team encountered, as well as how they solved many (not all) of these issues in some detail.

This chapter explains in detail how SERC's research project developed, beginning with an account of the various iterations of SERC's 'target', through which I begin to show how success and failure can be negotiated by interested actors. I then move on to a description of SERC's ADR technology (in particular, the guide star laser, adaptive optics system, and high power laser) in which I combine published materials with first-hand accounts to demonstrate how development was impacted at various points by a combination of technological, legal, and organisational challenges. In the second

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[400] (2021). New Laser to Help Clear the Sky of Space Debris. Newsroom, Australian National University.

[401] 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

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

part of this chapter, I pick up the thread of dual-use technology and show that although ADR is currently unfeasible both technologically and legally, this has not prevented continued investment in ADR internationally, presenting growing challenges for international and domestic law. I show how SERC used institutional structures to temporarily resolve some of the problems associated with the development of dual-use technology. Finally, I conclude this chapter by outlining how SERC, the structure that had enabled so much, was progressively disassembled as the organisation was wound up. I outline how SERC's participants divided up assets and IP, and how senior individuals and institutions successfully reframed attention away from SERC's failure to achieve its original stated goal, to instead claim, uncontested, that it was a success.

5.1 Constructing (fake) debris: a target for the demonstration

***Handmer**: Now, forgive this very simplistic question. But do you think it is possible to manoeuvre an object with photon pressure, using a laser?*

***Bennet**: Yes, definitely.*

***Handmer**: Okay. My understanding is, that it hadn't been done before, and still hasn't been done.*

***Bennet**: That's right.*

***Handmer**: What is the reason, that it may not have been done before?*

***Bennet**: No one has spent enough money on it.*

Francis Bennet, SERC

Originally, the planned culmination of SERC's activities was to be Research Program 4: the development of high power lasers, adaptive optics, and the "demonstration of remote manoeuvre of space debris and photon pressure".[403] Participating in the program were ANU, EOS Space Systems (EOS SS), Lockheed Martin (US), and National Institute for Information and Communications Technology (NICT) Japan.[404] However, for both technical and legal reasons (detailed in Section 5.3) it was difficult for SERC to proceed with the original idea of demonstrating the laser on a piece of actual debris. Instead, SERC's team decided to produce a piece of 'fake debris', equipped with sensors to measure the effect of the laser. The 2016 Annual Report provides technical justifications for why it was preferable to conduct the experiment on a controlled object, rather than a piece of debris.

> *Orbit manoeuvre options have been analysed with the view to determine how likely it will be to see and measure an orbit change. As a result, it has been concluded that to perform a quantifiable experiment it would be highly beneficial to put a controlled (and instrumented) target into space, rather than choose an uncontrolled object from the existing debris cloud.*[405]

The team decided to develop a new research program to "design and launch up to 3 cubesats [sic] with appropriate instrumentation on board to meet the requirements of the orbit manoeuvre".[406]

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[403] (2016). Annual Report 2015 - 2016, Space Environment Research Centre. p. 28.

[404] Ibid. p. 28.

[405] Ibid. p. 30.

[406] Ibid. p. 30.

The instrumentation part of Research Program 4, which included Bennet, was moved to Research Program 1, and Research Program 4 became entirely about the experiment demonstration. Lockheed Martin's Matt Bold, based in the USA, was replaced as Program Leader by EOS Space Systems' Ben Sheard (who was officially employed for this purpose by SERC) as program leader. Bennet explained that the change "made a lot more sense" because Sheard was "actually on-site" and "could actually then command the resources that they needed to be able to do". But by the release of the 2017 Annual Report, and in a review following that year's SERC colloquium, "the requirement to support the manoeuvre demonstration with a dedicated satellite was de-scoped".[407] Instead, the team planned to design and develop a "hosted payload which has an anticipated launch date in early 2018".[408] Bennet explained that, behind the definitive-sounding announcements made in each successive annual report, was a constantly shifting planning process that was anything but certain: "it moved to "do we do a high-altitude demonstration? Do we do a space demonstration?" Then it moved to its own CubeSat. Then it moved to a hosted payload".

The same changes to the research programs that modified the governance structure of the organisation had flow-on impacts for the technology development as well. A 2018 paper summarises briefly the technical changes that had to be made as a result of moving the instrumentation to Research Program 1.[409] Instead of purchasing an additional wavefront sensor (WFS) camera as planned, the team instead redesigned the instrumentation from Research Program 4, which was designed to allow for tracking and pushing of debris, so that it could function using the same WFS camera being used for the imaging work already being done in Research Program 1.[410] Re-structured and with an onsite team leader, the SERC payload (SPLD) was scheduled to launch on its host satellite on a SpaceX Falcon 9 rocket during November 2018 from Vandenberg Air Force Base, USA.[411] While waiting for the launch, when SERC would hopefully be able to test the AO system and high power laser on their satellite payload, SERC intended to test their AO system with a low power laser on a high-altitude platform — however, this never eventuated.[412]

The host satellite, 'Mission 1' ('M1'),[413] had been commissioned by the Royal Australian Air Force (RAAF) and built by engineers from University of New South Wales Canberra (UNSW Canberra) onsite at the ANU's AITC, Mt Stromlo.[414] The satellite's main mission was to provide surveillance, tracking, and identification services for "maritime traffic and aircraft", and develop the RAAF's Space Situational Awareness (SSA) capabilities for spacecraft in Low Earth Orbit (LEO).[415] A broader aim was to improve domestic capability in developing and operating Australian satellites.[416]

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[407] (2017). Annual Report 2016 - 2017, Space Environment Research Centre. p. 28.

[408] Ibid. p. 28.

[409] Korkiakoski, V., D. Grosse, B. Stone, M. Lingham, F. Bennet, C. d'Orgeville, T. Travouillon and C. Smith (2018). Adaptive Optics for Tracking and Pushing Space Debris: Performance of the Adaptive Optics System. 69th International Astronautical Congress (IAC). Bremen, Germany, International Astronautical Federation (IAF). p. 2.

[410] Ibid. p. 2.

[411] (2018). Annual Report 2017 - 2018, Space Environment Research Centre. p. 7.

[412] 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. slide. 22.

[413] (2018). Annual Report 2017 - 2018, Space Environment Research Centre. p. 33.

[414] (2018). RAAF M1 Satellite Prepares for Lift Off. School of Engineering and Information Technology, UNSW Canberra.; Biddington, B. (2019). Space Security in the 21st Century: Roles, responsibilities and opportunities for Australia. p. 229.

[415] Barraclough, S. (2017). RAAF - M1: UNSW Canberra - Royal Australian Air Force Space Situational Awareness and ISR Pathfinder Mission. 68th International Astronautical Congress. Adelaide, Australia.

[416] Ibid.

Like SERC, the launch of the M1 satellite represented a significant technological undertaking with political implications for Australia.

In June 2018 the Australian Minister for Defence Industry, the Honourable Christopher Pyne MP, visited UNSW Canberra to see the satellite ahead of its planned launch (see Figure 29).[417] In a departmental media release, Pyne aligned the planned launch with broader government investment in developing Australia's space sector, infrastructure, and human capability, explaining that projects like M1 represented "a unique opportunity to support Australian Defence Force capabilities and to rejuvenate Australian space industry". He added that "the Government is investing significantly in space-related projects for Defence over the next two decades".[418]

After several delays, the rocket carrying M1 finally launched in December 2018. In a vindication of SERC's overarching stated aim of improving satellite identification and tracking, the team working on M1 initially had trouble identifying which of the 64 satellites carried into space in this launch was theirs. Yet ultimately it turned out the team was unable to make contact with M1 altogether, "despite considerable effort and despite extensive tests. […] There are various lines of enquiry, but we may never know what the technical issue is", as Russell Boyce, Director of UNSW Canberra's Space operations, summed it up.[419]

Figure 29 — Minister for Defence Industry, The Hon Christopher Pyne MP, views the M1 spacecraft prior to launch.[420]

Ironically, with M1 SERC had indeed produced a new piece of space debris that might have served as their experimental target---but the experiment itself could not be conducted because the same simple component that made M1 unresponsive in general also disabled, more specifically, the measurement equipment required for the dislocation experiment. The SERC payload, consisting of "a pair of beacon assemblies to enable tracking and assessment of the adaptive optics system; and a pair of photodiodes to measure laser irradiance on-orbit", was located under a panel that was meant

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[417] (2018). M1 Satellite on Track for September Launch, Australian Government Department of Defence.

[418] Ibid.

[419] Boyce, R. (2019). "Update on the M1 Spacecraft."   Retrieved 02/03/21, from https://www.linkedin.com/feed/update/urn:li:activity:6514437076136660992/.

[420] (2018). UNSW Canberra CubeSat Set for Launch. Defence Connect, Momentum Media.

to “flap out” once M1 was in orbit, “exposing the solar panels and the antenna” which would have given the satellite both the power to function and the means to communicate. But due to a simple mechanical fault, the spring-loaded hot wire which formed the release mechanism “didn’t actually work, and so the panel could never flop out”. What is particularly interesting about M1 is that even though the satellite was, as Gower bluntly put it, “dead on arrival”, the team behind the project expressly and proactively denied that it was a “failure”. In fact, in his announcement, Boyce explicitly negotiated the very meaning of ‘failure’, and laid out the criteria by which M1 should be seen as a ‘success’ within a broader effort to develop Australia’s space capabilities.

> *So is the mission a failure? Absolutely not. M1, and the follow-on mission M2, are about tackling the difficult challenge of taking emerging technology and getting to the point where we safely and reliably operate it in the harsh environment of space, of embracing the associated risks and opportunities with an optimistic “can do” yet utterly professional attitude, and growing Australian skills and capabilities in the process. M1's issue is just a challenge along the way, one that we are using to trigger reflection and analysis of everything that we do and how and why we do it, and to get better and better as a result. M1 exemplifies why we (Australia, not just UNSW Canberra Space) need to fly often - and so our team is up-beat and looking forward to our next mission M2 launching later this year!*

My interest here is not primarily in the story of the M1 satellite project, although it is interesting to consider how it was cooperatively framed as a ‘success’ across politics, government, industry and academic organisations in the wake of what seems, on the face of it, a clear-cut technological failure. However, it is instructive to point out briefly the elements of this framing which foreshadow how similar entities likewise turned SERC’s technological failures into ‘success’. First, in a kind of apophasis, Boyce proactively confronts and denies ‘failure’, and in doing so, creates the scope in which, in the absence of ‘failure’, he will get to redefine what the mission was. Second, he frames M1 as just one component in a broader project, both by invoking ‘M2’ (a specific mission) and positioning M1 as a step along the path to ‘safe and reliable’ space operations. Third, and in a connected move, he establishes collective ownership over M1’s outcome, making it clear that ‘we’ refers to “Australia, not just UNSW Canberra Space”. Thus, the logical step is that if M1 is labelled as a ‘failure’, then the failure arose because Australia has not invested the necessary funds and policy support “to fly often” *enough.* Finally, with these stakes established, Boyce offers “us” (i.e. Australia) a way out by providing a range of alternate non-satellite reasons why we might see M1 as a success: lessons were learned, the skills and capabilities of Australian researchers (in both industry and academia) were improved, and M2 was now already underway.

But while it was possible for UNSW Canberra to sell M1 as a rhetorical success, the incident had real, practical implications for Research Program 4. Gower explained that because “M1 had failed”, and because their five years of funding would run out at the end of 2019, SERC was now under time pressure to find a back-up satellite on which to install a new payload. Gower “sent [Sheard] over to the Small Satellite Conference, or something, in the US, with the view of trying to find another launch”, and Sheard returned with a Canadian satellite mission that was “about the only one … that was within the timeframe of SERC, that we could actually jump on board”. In May 2019 Sheard left SERC,[421] and Craig Smith and Gower took over as co-leads of Research Program 4,[422] pushing ahead with the payload project. When I spoke to Gower in May 2020 the Canadian “Plan B” satellite was due to launch on a Rocket Lab rocket in late August 2020. Having learned their lesson from M1, SERC

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[421] (2019). Annual Report 2018 - 2019, Space Environment Research Centre. p. 20.

[422] Ibid. p. 33.

also organised “Plan C”, in case “Plan B never gets into orbit”: SERC’s partner organisation NICT gave SERC permission to test their laser on ‘RiseSAT’, a Japanese laser communications satellite which was already in orbit and came ready-equipped with infrared detectors. As this example illustrates, in the multi-layered context of Australian space science, a specific piece of technology might quite obviously fail to achieve its designated purpose — and yet there is considerable room to negotiate the social determinants of failure.

5.2 The experimental set-up: guide star laser, adaptive optics, high power laser

But ‘end’ is a bit like the horizon, you walk towards it but it’s kind of, you’re not quite getting closer to it.

Tony Travouillon

How were SERC researchers intending to demonstrate that laser ablation debris removal could be done? This section sketches the key technological components developed at SERC towards this purpose: the guide star laser which would be used to measure atmospheric perturbation, the adaptive optics system which would use mathematics, lenses, and mirrors to cancel out perturbations, the mirror that would shape the high power laser beam, and the high power laser itself. Each individual element contained its own set of unique challenges, and further problems arose in linking them to one another, to form a functioning ‘system’. My aim in investigating these development processes primarily through interviews rather than through the analysis of SERC’s technical publications was to provide an account of SERC’s working processes that highlights the relationships between instrumentation, theory, computer programs, and the people who worked with them. By doing so, the practical challenges that arose from working within SERC’s particular research, organisational, financial, and social structure that would otherwise be invisible to an outside observer become apparent.

At its simplest, Bennet explained in our interview that pushing an object in orbit with photon pressure requires three things: “a large telescope on the ground”, “an extremely high-performance adaptive optics system”, and “a state-of-the-art laser”. At the time SERC began, EOS already had a high power laser, and had begun work on a guide star laser, “and they had a path to increase the power to both of those”. The fourth component that Bennet identified as necessary to complete an “actual operational system” was “half a billion to a billion dollars” in funding. If all you needed to achieve was a demonstration (which would, as Travouillon put it, demonstrate that it could be done, rather than necessarily *doing* it), and taking into account EOS’s existing equipment and the addition of ANU’s equipment at Mount Stromlo, Bennet estimated that you’d still need to spend somewhere between $50 million and $300 million. In his opinion, laser debris removal was technologically and theoretically possible, but the chances that SERC could achieve it with the funding and technological resources they had to hand was “still, like, dubious”. Nonetheless, even in early-to-mid-2020, when Research Program 4 had still not found or produced a viable piece of fake debris on which to test the debris removal laser (though it had, in the meantime, contributed to the creation of an additional piece of real space debris in the form of the non-functional M1 satellite), work continued on the ground-based instrumentation that would be required to complete the experiment. A key focus was developing a better, more predictive adaptive optics system.

In an explanation published by members of 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.[423] The experimental supersystem is depicted in Figure 30 and the subsystem diagram in Figure 31. The telescope would use reflected sunlight on a space object — “natural guide star light” — to track it across the sky.[424] 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.[425]

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.[426] The two institutions would work together in a “collaborative effort that uses expertise from both the ANU and EOS teams”.[427] Work on the guide star laser (GSL) was led by Dr James Webb, originally employed at EOS Space Systems,[428] and later by ANU RSAA. Like Biddington and Ball, Webb had a military background, having graduated as an electronics engineer with the RAAF.[429]

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),[430] shown in Figure 31 as an orange box and in Figure 32 in detail.[431] Bennet was convincing in his description of how “all these components, individually, are challenging on their own”, and that they were even more complicated together. 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.[432] Bennet, who worked on the instrumentation, explained that “there are no nice ways” to ‘excite’ sodium at 90km altitude because “there are no known materials” which will ‘lase,’ i.e. resonate with sodium atoms at the specific frequency of 589 nanometres. In addition, the high wattage required to

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[423] 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.

[424] Ibid. p. 2.

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

[426] 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.

[427] Ibid. p. 1.

[428] (2016). Annual Report 2015 - 2016, Space Environment Research Centre. p. 13.; (2017). Annual Report 2016 - 2017, Space Environment Research Centre. p. 12.; (2018). Annual Report 2017 - 2018, Space Environment Research Centre. p. 15.; (2019). Annual Report 2018 - 2019, Space Environment Research Centre. p. 15.

[429] (2018). Annual Report 2017 - 2018, Space Environment Research Centre. p. 15.

[430] 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.

[431] Ibid. p. 2.

[432] Ibid. p. 2.

operate a guide star laser like the 20-watt continuous wave laser that EOS contributed requires a very specific power source.[433]

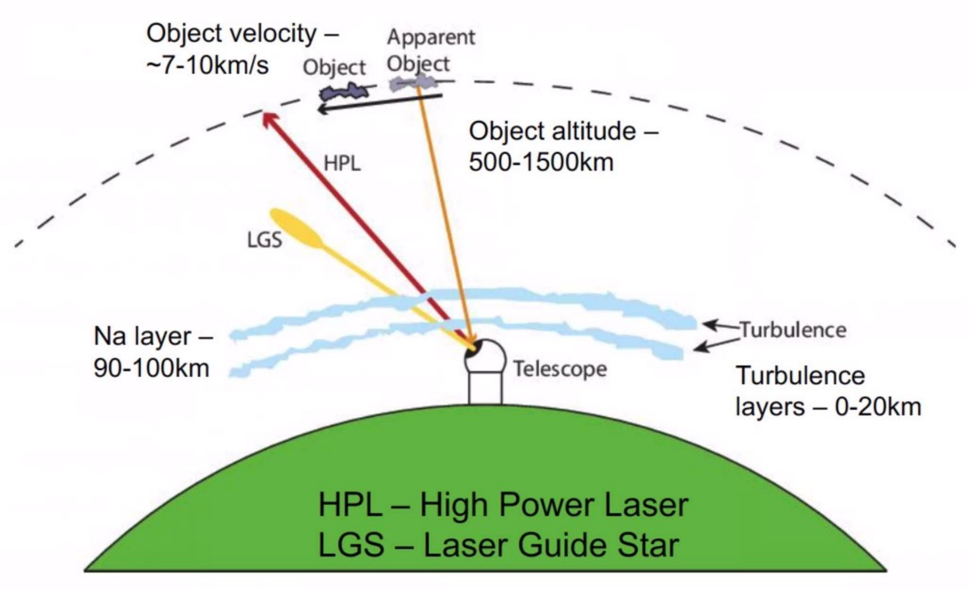

Figure 30 —Diagram of the proposed SERC experiment supersystem showing intended interplay between components. [434]

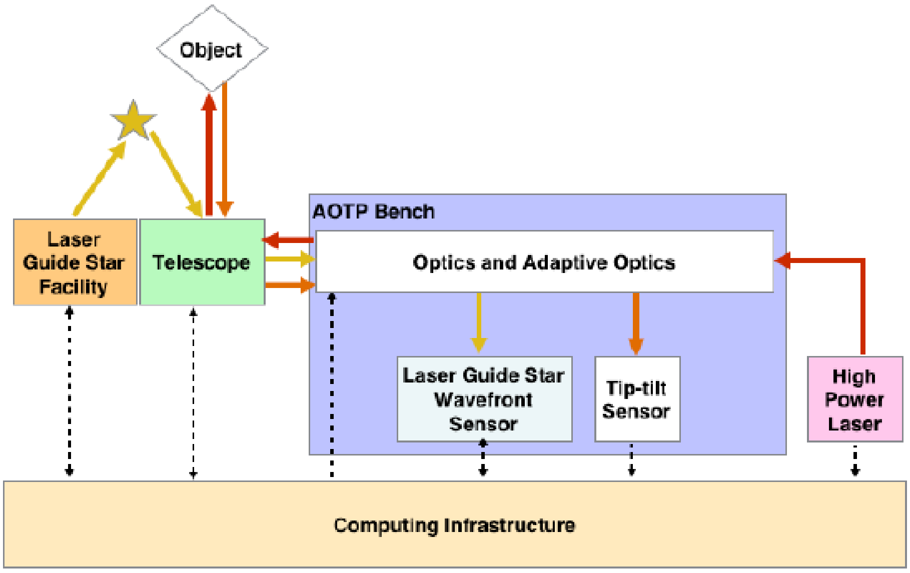

Figure 31 — Subsystem structure of the SERC experimental setup showing interface between the LGS / GSL and the other components. The optical interface is shown in orange, yellow and red, and the software interface is represented by dashed black arrows.[435]

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[433] Ibid. p. 2.

[434] 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. presentation slide. 8.

[435] 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.

Despite these technical difficulties, a person relying only on the updates provided in SERC's Annual Reports would get the impression that although there were delays, the development of the guide star laser went smoothly and occurred in a linear fashion, from design to construction, testing, and installation. According to the official record, 2016 saw the completion of the guide star laser design, and by this time "the build of hardware and control software is underway".[436] In 2017, SERC reported "significant progress with the Guide Star Laser", citing that the installation of a new amplifier and "additional control system developments" had "cleared the final hurdles" to achieve the required "wavelength and power output".[437] In 2018, the team provided a comprehensive report which highlighted that efforts were now focused on "repackaging the laser and integrating it with the [adaptive optics] system", and relocating "vibration sensitive GSL oscillators from the side of the telescope to the cleanroom". The report also discussed "mounting brackets", "support infrastructure such as chillers and equipment racks", and "fabrication" of the guide star laser "enclosure".[438] The final report, published in 2019, states that the guide star laser was finally "relocated to the telescope laser lab from the AITC" in October 2019 and that "control electronics" were undergoing testing.[439] It predicted that "Installation and commissioning on the 1.8 m telescope will take place in the fourth quarter of 2019".

However, the official reports do not reflect what proved to be the decisive challenge in making several technologically sensitive systems 'talk' to one another. The integration of sophisticated tracking technologies also required organisational, social, and structural factors to align as precisely as the technological systems. As these alignments were being negotiated, the development of the guide star laser was characterised by numerous set-backs and changes in direction.

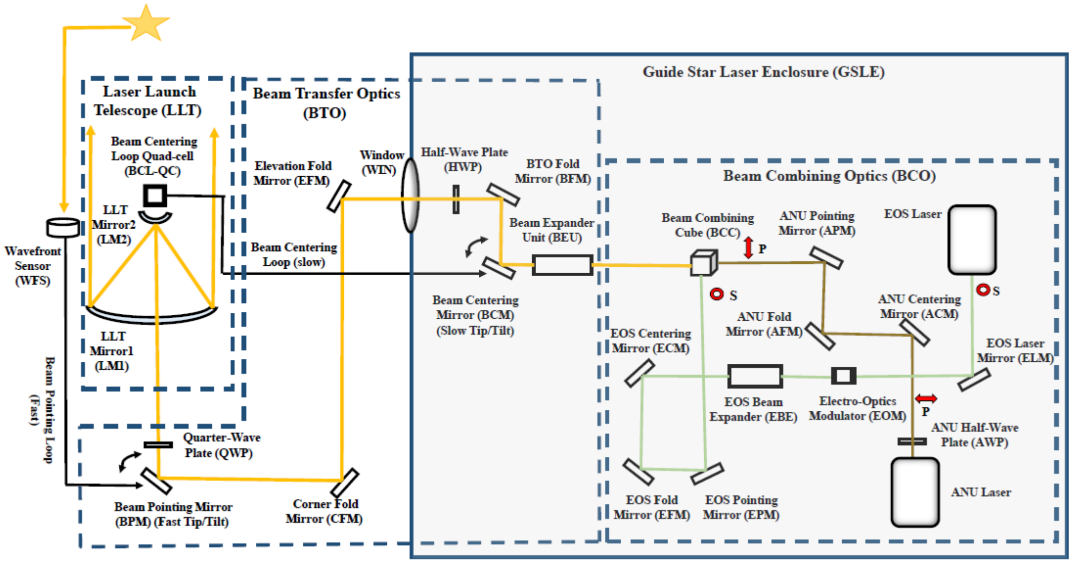

Figure 32 — Diagrammatic representation of the Laser Guide Star Facility.[440]

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[436] (2016). Annual Report 2015 - 2016, Space Environment Research Centre. p. 29.
[437] (2017). Annual Report 2016 - 2017, Space Environment Research Centre. p. 21.
[438] (2018). Annual Report 2017 - 2018, Space Environment Research Centre. p. 23-24.
[439] (2019). Annual Report 2018 - 2019, Space Environment Research Centre. p. 27.
[440] 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. 3.

When Travouillon arrived at ANU (and thence SERC) in 2018 he was asked to oversee the process of commissioning and integrating the instruments that made up the LGSF. As work progressed, it was decided that in addition to the 'bench', the ANU team and the EOS team would each provide a laser whose beams could be combined or used separately ('ANU Laser' and 'EOS Laser' in Figure 32).[441] When we spoke in June 2020 Travouillon referred to this part of the project as an example of the sort of problems he encountered. Specifically, Travouillon was referring to the "part of the optics where we supply a laser to EOS, they supply another laser, and then we combine them onto an optical table and then send that to the telescope"; or, in more technical terms, the operational interface between the Beam Combining Optics (BCO) and the Beam Transfer Optics (BTO). The issues that Travouillon highlighted were not technological ones, but instead arose from the human side of the process of producing technology. He explained how miscommunications and misunderstandings occurred between EOS and ANU as to who was responsible for what aspect of the process, requiring both sides to "take a step back" and "kind of reset".

> *… the responsibility of the beam combiner, who was doing what, was I thought clear, that we were handling it on our side, with very specific requirements from EOS's side. And in the end it turned out they, they also thought, they were also going to contribute to that design. We didn't talk about it, because for them it was clear, for us it was clear, but it was not the same message, the actual work wasn't exactly lining up.*

The complexity of bringing together individuals from different disciplines who worked for different organisations was a constant challenge for students, researchers, and management alike. In some ways, the problem was compounded by the way the research programs were structured intentionally around networks of interdependence — each researcher's "outputs are inputs for someone else". Gower's view was that "by and large people don't want to stuff other people around", and that the construction of interdependence shaped around outputs required researchers to take responsibility for forming and managing cohesion earlier in the design and production process. SERC's social structure was an important part of the operational picture, but others I interviewed pointed to structural factors that interfered with the ability of individuals to meet social obligations even where they may have wanted to. For example, Bennet explained that both he and EOS staff, as individuals, wanted "to move that same research program along", but that at times EOS staff were "required to go and work on something which is paying the bills", and could not focus on SERC work. He elaborated on the differences in corporate structure between institutions, and how they affected the individual and collective prioritisation process.

> *I think that EOS were able to bring a lot to the table for the projects we were collaborating on. But at the same time, they had commercial interests which sometimes interfered with the research interests - which is understandable. They have to put food on the table, whereas ANU has a little bit more backing. We can probably survive a little longer without contracts being fulfilled.*

On the other hand, Gower noted that while SERC's academic researchers may not have had contract deliverables in the same way that their private sector partners did, they were nonetheless hampered by competing deadlines driven by financial imperatives. The scarcity of reliable funding sources for academic research meant that researchers were regularly applying for (and winning) grants, each with their own attached research obligations, during the time that they might otherwise have been working on SERC research. Gower recalled reading in "research highlights" in his quarterly reporting proforma that university participants had, for example, "applied for an ARC grant". While he felt that

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[441] Ibid. p. 2.

the financial setup of the Australian universities was the key issue, not the individuals themselves, he saw such activity as being outside the scope of SERC's remit, and a distraction from research obligations: "I'm not interested if you're applying for an ARC grant. That's on your time, not on my time!"

At times during SERC's operation, the combination of siloed work, competing priorities, and irregular information sharing resulted in the perception that further work from one partner was futile because the other partner could not provide their output in time. While some researchers I spoke to remained convinced that it was truly pointless for them to carry on working, Gower explained to me that in his view it was actually the mistaken *perception* that other parties were not meeting deadlines that caused some teams to slow work down or focus on other projects. These delays were what he saw as causing missed deadlines, rather than work actually running behind. As General Manager, Gower at times stepped in to break the deadlock with "some very stern words".

Equally, from my perspective as an outsider, it was clear that there were some technical problems that were not merely imagined, and that caused tangible changes to the work program. There was a mismatch in perceptions between those on the corporate side of SERC's operations and those on the research side. For the administrative and management staff, the best (and only administratively defensible) approach was for everyone to act as if projects were going to plan until they were informed through the formal reporting processes that there were delays. For the research staff who had specific technical expertise, they could predict well before a formal process was triggered that there would be delays because they could actually *see* the minute technical challenges that would be totally invisible to anyone else. The misalignment in approach, both sides of which were entirely logical, resulted in frustration for everyone.

The laser guide star facility itself was a salient example, going through "several, significant design changes from their original design",[442] and ultimately pushing out the timeframes for when the experiment could be attempted, to beyond SERC's 5-year funding term. When I spoke to Bennet to try to dig down into what the problems were, he explained that the EOS guide star laser itself had ongoing technical challenges, which meant that although it was "getting there" when we spoke in May 2020, he predicted it would take "another year or two [from 2020] before it is fully operational". Bennet's team, working on the Adaptive Optics Imaging (AOI) system which sat on the adaptive optics Bench (shown in purple in Figure 31), experienced the practical implications of delays in the delivery of key hardware. Originally, Bennet explained that the team designed a microlens array "to be able to be switched between" the laser guide star interface, in "LGS mode",[443] and the natural guide star interface (which would use "the satellite itself as the beacon"). After years of delays, waiting to be able to integrate the guide star laser, Bennet recalls that the ANU team and the leadership decided to "make that call and say, 'all right, it's clear this laser isn't going to be delivered; we're now just going to modify our design, so it's going to work' in some fashion" (i.e. with the natural guide star).

Where Bennet-the-instrumentation-scientist, saw the problems and their solutions as being mainly technical, and Gower-the-General-Manager focused on how different institutional priorities and incentives (particularly funding) slowed down research and could be overcome with managerial intervention, Travouillon's view as Project Manager was that "the challenge was people, actually". He felt that "getting everybody in the room and pushing through [problems] is what was very

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[442] Bennet, F. (2020). Research Interview. HREC 2020/145. A. Handmer.

[443] Copeland, M. (2020). Satellite and Debris Characterisation with Adaptive Optics Imaging. Doctor of Philosophy, Australian National University. p. 74.

difficult". The problem was compounded by challenges with continuity, as key members of SERC's research staff came and went during the project, making it "really difficult to make sure the knowledge retains and percolates". Sitting between the corporate and research functions of SERC, Travouillon saw the delays as also resulting from a mismatch in the "pace" of work. Mismatched 'pace' resulted in breakdowns in SERC's governance processes: as Bennet put it, "if you go to a meeting and week after week everyone just says 'well, there's no progress', what's the point of holding a meeting?"

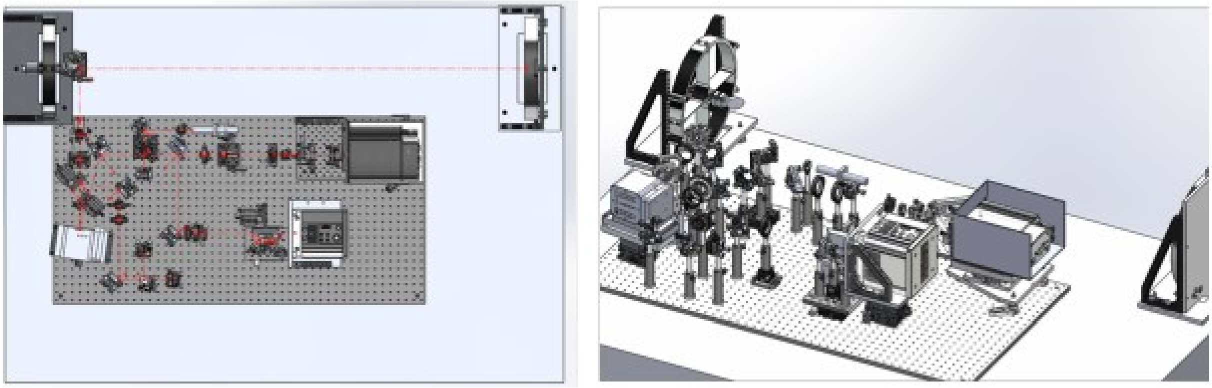

Figure 33 — A diagrammatic representation of the mechanical layout of the SERC Adaptive Optics Imaging (AOI) system. On the left is a view from above, while the right shows a trimetric view.[444]

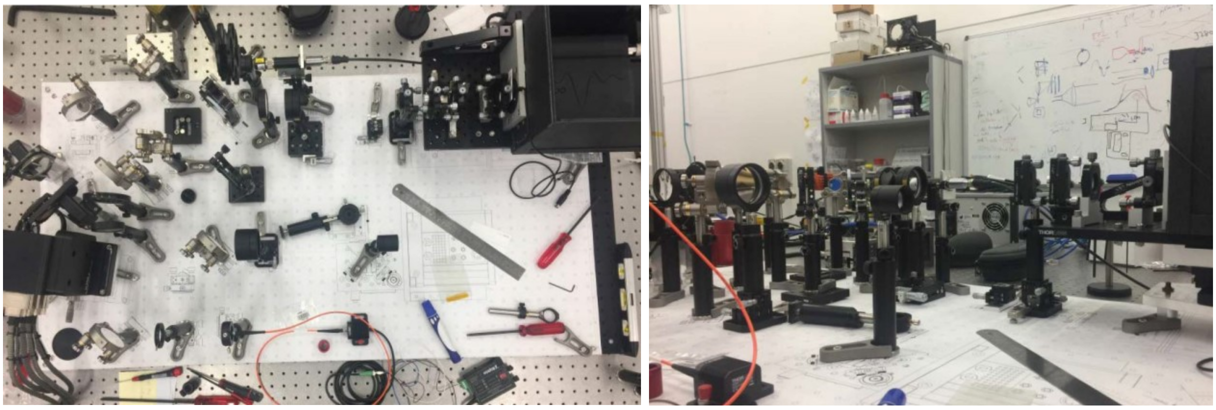

Figure 34 — Based on the design depicted in the diagrams in Figure 33, the SERC researchers had to manually construct the array. Here the components are being physically aligned and screwed into the 'bench'. Every time decisions were made up-the-chain about what the 'demonstration' would entail, physical changes had to be made to the set-up.[445]

Part of the 'pace' issue arose from technical problems, and part of it from trying to find the best ways to collaborate across institutions which had "different rules", different ways of working, and different priorities, which he described with the word "connectivity". When we met in June 2020, Travouillon explained that EOS still hadn't delivered some of their key "hardware deliverables", including a laser and a deformable mirror.

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[444] Copeland, M., F. Bennet, F. Rigaut, C. d'Orgeville, V. Korkiakoski and C. Smith (2017). Satellite and Debris Characterisation in LEO and GEO Using Adaptive Optics. Advanced Maui Optical and Space Surveillance Technologies Conference. Maui, USA, AMOS. p. 5.

[445] (2018). Annual Report 2017 - 2018, Space Environment Research Centre. p. 23.

> *We are waiting for that to be delivered, and they really struggle and struggle. So, you know, you're working at one pace, which is your internal pace, and you have to adapt to somebody else's pace … Sometimes you have to work out, we are going too fast, we have to slow down, or do we push ahead and wait for them? Can we help them? Like we helped, for example, with the alignment of the telescope which was an issue. Because when the telescope was built, it was never thought that we would need such a high level of accuracy in the way we track objects.*

This perspective, that solutions to technical problems depended on social organisation, and that each design change necessitated additional practical work to adapt the instrumentation accordingly, was mirrored in a slightly different way by Cranney, a PhD student working on the software side of the Adaptive Optics Imaging system (shown in yellow in Figure 31). Cranney saw himself as a kind of 'translator'. His job was to find ways of using control theory to "do some clever prediction that will improve the optics performance" of the adaptive optics system. He worked with the software that gave commands to the deformable mirror (a crucial part of the set-up by which the laser beam was precisely shaped in response to the adaptive optics system), and rather than using the most recent guide star measurements (which were always "kind of outdated") Cranney's software tried to incorporate "things that we know — like the physics of the atmosphere, or the fact that the telescope might be moving across the sky" to pre-emptively shape the mirror. He explained to me that the delay between the moment that the guide star system senses the atmospheric turbulence and the time that the mirror deforms "might be 2 milliseconds", but when you're "slicing through the atmosphere with the telescope", 2 milliseconds is too long.

> *… it's always like you're just trying to fight the next bottleneck, in the control system. And, I guess, the last two decades the bottleneck has started being this temporal aspect. The evolution of the turbulence. So if we can fight that, then it becomes the next thing, and then you tackle that problem.*

Cranney described his research as being "very compartmentalised", and "hands off the physical problem".

> *I just need to know physically what the problem is, I don't so much play around with the optics. Which is a bit of a shame, because it looks super fun up there. I've been up the telescope, once or twice, and it's always like … I'm always starstruck, to see all these physicists working on this cool stuff. I'm, kind of like the engineer. A bit less, hands on. I would say.*

During his PhD research Cranney worked in Newcastle on "the current version of the problem", and would travel to Mount Stromlo every few months, "recalibrating with the physicists about the actual problem". In the process of learning about optics and speaking to various team members, Cranney was himself an outsider, and like Travouillon, he noticed that the teams he was working with "weren't often talking to each other". He identified that even outside of the organisational delineations between ANU and EOS that Bennet, Gower and Travouillon pointed out, there were also divisions at SERC between scientific specialties: each "field" had "their own kind of language and semantics". Cranney explained how these language differences caused delays and confusion in developing the adaptive optics system, not just because the mechanical components had to interface with software components, but because "the physicists" had to communicate meaningfully about technical requirements with "the control theory guys", translating a "physical goal" into a "mathematical control objective". In his case, understanding what "this thing called the Strehl ratio" meant (a measure of post-AO image quality) and "how that applies to some kind of optimisation task in control theory" in order to agree what the goal of the task was "probably took the better part of six months".

While Cranney was focussed on the coding side of the loop, Travouillon, Bennet, and Gower were occupied with a very tangible problem — ensuring that the mirror was physically capable of withstanding the laser beam and forming the correct shapes. In theory, the light detected by the telescope bounced off a primary mirror and then travelled along a coudé path, a term used to describe the design of telescopes which redirect the beam of light via a series of mirrors so that the telescope can move freely without affecting the focus point.[446] In SERC's case, the coudé path directed the beam "down a chain of five other mirrors into the lab" (see Figure 35), which was vital because the EOS telescope needed to slew quickly while tracking objects across the sky. Bennet explained that aligning the large mirrors was "quite tricky", made more so by manufacturing issues with two of the key mirrors that sat in the Laser Launch Telescope (LLT) — the deformable mirror (shown as 'DM' in Figure 35) and the beam expander mirror (shown as 'M2' in Figure 35).

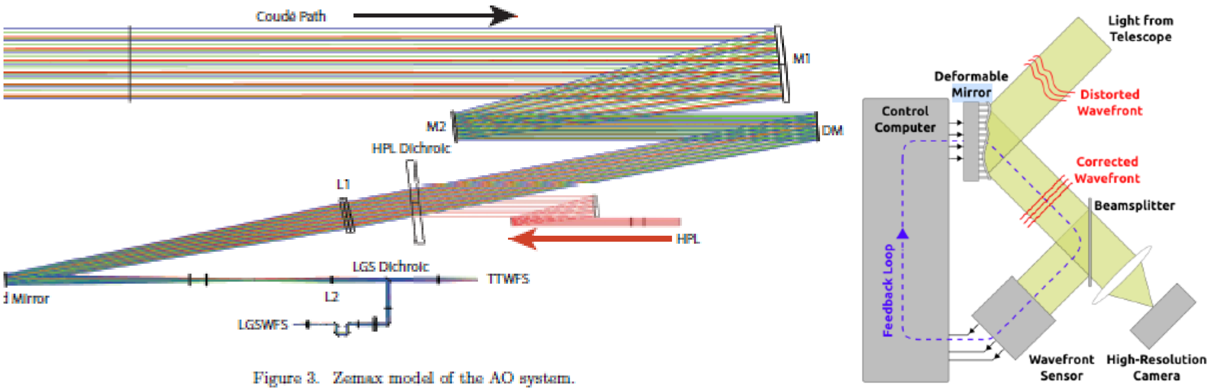

*Figure 35 — **Left**: diagrammatic representation of the path of light from the telescope along the coudé path. 'HPL' stands for 'high power laser', and 'LGS' for 'laser guide star'. 'M2' is the beam expander mirror and 'DM', the deformable mirror, was a larger mirror that physically changed shape in response to inputs from the adaptive optics loop. **Right**: Interface of deformable mirror with the adaptive optics system. Cranney's PhD research contributed to the 'control computer' which gave instructions to the deformable mirror using a combination of predictions and historical observations.*[447]

Bennet explained to me that most of the instruments that were purchased off-the-shelf for SERC worked "out of the box", but the two mirrors were exceptions. The problem with the beam expander mirror was relatively straightforward: the mirror was damaged "during the last stages of manufacture", which meant that it had to be re-ground and re-polished. The process delayed delivery of the mirror to late 2019, which was close to the end of SERC's operational period.[448] The deformable mirror, on the other hand, presented an ongoing saga of complications. The mirror was manufactured by a US company called Xinetics, a branch of Northrup Grumman which makes

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[446] Dhillon, V. (2010). "Coudé and Nasmyth." Department of Physics and Astronomy Retrieved 26/09/2021, from http://www.vikdhillon.staff.shef.ac.uk/teaching/phy217/telescopes/phy217_tel_coude.html.

[447] 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.

[448] (2019). Annual Report 2018 - 2019, Space Environment Research Centre. p. 13.

adaptive optics components and systems.[449] In 2017 the SERC Annual Report flagged that there had been issues with the deformable mirror that needed to be resolved and that “repolishing / recoating work” had begun.[450] By 2018 the deformable mirror had been repolished and “preparations for recoating are underway”.[451] But progress remained slow, and by 2019 the issue of the deformable mirror had been included in the section that formally reported “risks and impediments”.[452] The report stated that recoating had been delayed “due to the unserviceability of the coating machine at ANU”, but that coating of test samples had begun and that the mirror was expected to be recoated in October 2019.[453]

Bennet explained to me that the reason the mirror needed to be repolished and recoated was that damage had occurred to an actuator during manufacture which gave the mirror a permanent “feature” that couldn’t be flattened.

> *… the actuators are glued to the face-sheet. One of the spots of glue, had been overstressed, at some point, and it had slightly elongated by about three microns. And so, that was too much … I mean that’s about five times the wavelength of the light that we were correcting, so, that’s a huge amount. So we couldn’t actually flatten the DM at all, there was always this feature on there.*

Given the significant cost of the mirror (roughly US$700,000), SERC decided to send it back to the US to have the coating removed, and the mirror repolished, which then meant that they needed to apply a fresh coating to the repaired mirror. ANU had a facility that coated mirrors, run by EOS. Since the mirror would be required to reflect a uniquely high amount of energy, the team opted to do the coating in-house so that they could test different options as they went. Travouillon explained the technical challenge:

> *Basically what we are trying to do is send a very high powerful laser beam, which has a lot of watts of energy, so it can get things very hot, on a deformable mirror, which has a very thin membrane [which] can obviously take a lot of heat. And the coating for that mirror had to resist and reflect all that heat away. All that energy had to be basically reflected, and that was fairly challenging for EOS and the people involved in that.*

However, by May 2020, (well beyond when the 2019 Annual Report said the mirror would be coated), Gower informed me that work had stopped on coating efforts because the researchers were barred from entering the specialist ANU facilities due to lockdowns in response to the COVID-19 pandemic. But even outside of pandemic-induced delays, Bennet explained that after eighteen months of testing different coating methods, a solution still hadn’t been found: “none of them have worked. It has ended up failing every time”. According to Bennet, “the reason that the coating is failing, is that you have to do it at low temperature, because the deformable mirror face-sheet is literally glued onto the actuator. So, if you heat it up too much, the glue will melt and the face-sheet will slide off”. SERC’s Final Report, released in 2021, states that “SERC researchers have developed cold coating techniques which will allow the DM surface to be coated whilst still attached to the actuators”, but that test coatings were still being done “to ascertain whether the coating has the

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[449] (2020). "AOA Xinetics." Retrieved 21/09/21, from https://www.northropgrumman.com/who-we-are/aoa-xinetics/.

[450] (2017). Annual Report 2016 - 2017, Space Environment Research Centre. p. 21.

[451] (2018). Annual Report 2017 - 2018, Space Environment Research Centre. p. 23.

[452] (2019). Annual Report 2018 - 2019, Space Environment Research Centre. p. 13.

[453] Ibid. p. 13.

necessary reflectivity (R) at the requisite wavelengths, and to measure the laser damage threshold".[454]

Travouillon felt that the mirror, which he called a "massive headache", was one aspect of SERC's operations that was "clearly underestimated, in terms of how complex it was". Where the challenges with the adaptive optics system had arisen from issues with connectivity between teams and misalignments between the 'pace' of work from various institutions, Travouillon presented the problem of the mirror as a purely technological one. Nonetheless, the attempted solution — that the team had to "basically go back to the Board and say, 'hey, this is more problematic than we thought'", and ask for more resources — drew on SERC's organisation and financial structure.

Biddington, who sat on the board and would have received submissions from Travouillon and the team about the mirror issue, confirmed that the broken mirror was one of two significant issues that delayed experimental readiness. As usual, Biddington was keen to draw my attention to the broader picture, explaining that the problem had a more significant effect than it might otherwise have done because of capability gaps in the Australian space sector (there were few people or organisations able to resolve technical issues of this nature), and that this was one of the strategic issues that SERC, by its existence, aimed to address. Thus, as Biddington framed it, the fact that there was a technological failure (a very expensive mirror that could not be used) which significantly impeded SERC achieving its goal (the laser debris manoeuvre) was not itself a failure, but an important opportunity for SERC, and therefore EOS, ANU, and, by extension, Australia, to develop the domestic capability to solve such problems in future. The development opportunities that SERC afforded to institutions and their personnel through this, and other, technical challenges, was part of what made SERC a success in Biddington's eyes.

Where some of SERC's delays were purely technological problems, the high power laser(s) that were vital to SERC's experimental design caused delays for reasons that were as political and commercial as they were technical. The high power laser would be shone back down the coudé path through a dichroic, bouncing off the deformable mirror, the beam expander, and the primary mirror to direct photons back out through the telescope into the sky. Much of the technology SERC developed and worked with could be classified as 'dual-use' but none more so than the 10kW infrared laser that Lockheed Martin US lent to SERC so that they could undertake the photon pressure part of the planned experiment. As previously noted, at 10kW, the high power laser (HPL) was so powerful that it necessitated the development of new coating techniques for the deformable mirror that would reflect and shape its beam before it was sent down the telescope and into space. Originally, SERC had discussed developing their own high power laser,[455] but by 2016, SERC was "looking to use an existing laser instead of designing and building one from scratch",[456] and Matthew Bold, a Principal Researcher with Lockheed Martin Space Systems with an academic background in high energy particle physics and laser propagation,[457] began the process of "working with internal property control and export control experts" to try to get US government permission to send the laser to Australia.[458]

Even if SERC had successfully branded their operations as a civil exercise in cleaning up the space environment, the US Department of State proved harder to convince. The export of technologies

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[454] (2021). Final Report 31 March 2021, Space Environment Research Centre. p. 26.

[455] (2015). Annual Report 2014 - 2015, Space Environment Research Centre. p. 21.

[456] (2016). Annual Report 2015 - 2016, Space Environment Research Centre. p. 30.

[457] (2017). Annual Report 2016 - 2017, Space Environment Research Centre. p. 17.

[458] (2016). Annual Report 2015 - 2016, Space Environment Research Centre. p. 29.

with military application is governed by strict US legislation called the International Traffic in Arms Regulations (ITAR), designed with the purpose of "safeguarding US national security and furthering U.S. foreign policy objectives", to "protect its national interests and those interests in peace and security of the broader international community".[459] The key difficulty for Bold (and SERC) was that the specific laser Lockheed Martin wanted to send to Australia had originally been developed as part of a weapons system. Their 10kW laser, now no longer in use, was a prototype of the 10kW laser system used to develop Lockheed's Area Defense [sic] Anti-Munitions system (ADAM). ADAM used "an off-the-shelf 10-kW laser from IPG",[460] a fibre laser first available for sale in 2009.[461] IPG Photonics manufacture fibre lasers and amplifiers "for diverse applications in numerous markets", including "advanced applications" such as laser weaponry.[462] The first test of ADAM was conducted in 2012,[463] and reported in Lockheed's 2013 Annual Report.[464] During the test, the prototype system "burned through compartments in the rubber hull of two military-grade small boats maneuvering [sic] in the ocean at a distance of a mile in less than 30 seconds".[465] In 2013, the system "shot down eight free-flying Qassam-like rocket targets in tests at a distance of almost a mile".[466] ADAM had "shown that 10kW is adequate to defeat simple threats",[467] but Lockheed Martin Space Systems continued to make improvements, combining multiple fibre lasers into one 30kW beam,[468] called Accelerated Laser Demonstration Initiative (ALADIN).[469] By 2014 they had produced the prototype Advanced Test High Energy Asset (ATHENA) which was a direct upgrade to ADAM.[470] At the time I was conducting this research, ATHENA was listed on Lockheed's website as one of their products, advertised as "providing great efficiency and lethality in design" to "defeat close-in, low-value military threats such as improvised rockets, unmanned aerial systems, vehicles and small boats".[471]

Lockheed therefore no longer needed their spare 10kW IPG laser, which was, even by 2014, an 'off-the-shelf' item,[472] but it was still a significant challenge to get the necessary US government permission to import it to Australia. When we spoke in 2020 Bennet was still amazed that they

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[459] (2019). "Getting Started with Defense Trade: The Directorate of Defense Trade Controls (DDTC) and the Defense Trade Function." Retrieved 08/07/2015, from https://web.archive.org/web/20150708002117/https://www.pmddtc.state.gov/documents/ddtc_getting_started.pdf. pp. 1-2.

[460] Extance, A. (2015). Laser Weapons Get Real: Long a staple of science fiction, laser weapons are edging closer to the battlefield, thanks to optical fibers. Nature Magazine, Scientific American.

[461] (2009). IPG Photonics Successfully Tests World's First 10 Kilowatt Single-Mode Production Laser, IPG Photonics Corp.

[462] (2021). "The World Leader in Fiber Lasers." Retrieved 10/03/21, from https://www.ipgphotonics.com/en#[about-us.

[463] (2016). Lockheed Martin Advances Directed Energy Programs: Laser Weapon System (LWS) Milestones & Key Events, Lockheed Martin Corporation.

[464] (2013). Lockheed Martin Corporation: 2013 Annual Report, Lockheed Martin. p. iv.

[465] Coffey, V. C. (2014). High-Energy Lasers: New Advances in Defense Applications. Optics & Photonics News, OSA: 30-35. p. 34.

[466] Ibid. p. 34.

[467] Ibid. p. 34.

[468] (2018). "ATHENA Laser Weapon System Prototype." ATHENA Retrieved 11/03/21, from https://www.lockheedmartin.com/en-us/products/athena.html.

[469] (2016). Lockheed Martin Advances Directed Energy Programs: Laser Weapon System (LWS) Milestones & Key Events, Lockheed Martin Corporation.

[470] (2018). "ATHENA Laser Weapon System Prototype." ATHENA Retrieved 11/03/21, from https://www.lockheedmartin.com/en-us/products/athena.html.

[471] Ibid.

[472] Coffey, V. C. (2014). High-Energy Lasers: New Advances in Defense Applications. Optics & Photonics News, OSA: 30-35. p. 31.

managed to do it at all, telling me that the process took eighteen months and involved “a lot of legal paperwork”. But when I visited SERC’s offices in 2018 and again in 2019, the Lockheed Martin 10kW laser remained in its packaging. Rather than integrate the 10kW laser lent by Lockheed for the demonstration, EOS decided to build their own high power laser. Based on his experience with the guide star laser program, Bennet thought that the decision was likely driven by EOS’s desire to create their own high power laser IP, which he saw as a “commercial priority for them”. EOS could have opted to buy a commercially available guide star laser, but by developing their own guide star laser “they could get SERC to pay them, to generate this IP. And then they get to own it, at the end”.

Gower confirmed that SERC purchased four 2kW laser modules which were then combined using polarisation and spectral combination to form a single 8kW laser. While the fact that SERC was “willing to pay them to generate IP” offered an opportunity for EOS to develop their own high power laser while reducing commercial and financial risk that might otherwise have been associated with the project, the program still had to manage significant technological and safety risks. Bennet explained:

> *… once you have 8 kW of laser power, you have to have very careful consideration for laser safety, you have to consider everything else that is in the lab. I mean, if a tiny bit of beam goes through your mirror, or beam splitter, something is going to be set on fire, you’re going to put a hole in the wall, that’ll be, you know, 100 mm in diameter, not a tiny little speck, like you’d normally expect.*

A significant issue for SERC’s Board to consider was how a 10kW laser could be deployed from the Mount Stromlo site in a way that was safe, and compliant with relevant law and policy. While personnel on the mountain could be kept safe through regular procedures, there was a risk that the laser would strike (and damage) an aircraft *en route* to space. 10kW of infrared laser is not powerful enough to instantly incinerate a target, but it could heat up an aircraft enough to set it on fire, or melt components.[473] In our interview, Biddington explained that his main concern as a Board member was that the visible (guide star) laser might inadvertently blind a pilot. However, lasers are frequently operated from Mount Stromlo, and standard mitigation measures include issuing a NOTAM to restrict flights over the area, and a visual check for aircraft prior to deployment. In addition, publications on the proposed SERC system refer to technological safety controls such as the Aircraft Detection Camera, which is permanently mounted on the telescope and “inhibits all laser emissions if any object higher in temperature than the sky background enters the frame”.[474]

The plan, as outlined in the 2017 Annual Report, was for SERC to eventually combine the SERC 8kW laser and the Lockheed 10kW laser and use the resulting beam “for the on-sky experiments to move a piece of space debris”.[475] When we spoke in May 2020, Biddington said that SERC would ship the 10kW laser back to the US later that year. At that time, Bennet was unsure as to whether the integration would occur, but he thought it unlikely, particularly in light of the delays with the

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[473] In fact, the high power laser that SERC borrowed from Lockheed was, after all, developed with this very idea in mind see Sections 5.2 and 5.3 for more detail). Videos can be found online of the operationalised versions of the SERC laser, the ADAM and ATHENA systems, disabling airborne targets. See, for example, the videos: (2017). ATHENA Laser Weapon System Defeats Unmanned Aerial Systems. https://www.youtube.com/watch?v=hNsUtZmWgdg, Lockheed Martin.; (2012). ADAM High Energy Laser Counter-Rocket Demonstration. https://www.youtube.com/watch?v=3pO2A5oJyX0, Lockheed Martin.

[474] 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. 12.

[475] (2017). Annual Report 2016 - 2017, Space Environment Research Centre. p. 21.

deformable mirror. However, Bennet expressed his opinion to me that Lockheed Martin knew that their laser "was never going to go on-sky, with the EOS telescope", but sent it anyway, because "they didn't want to be seen as holding anything up". As Bennet explained, there was "years of work that still needs to be done" to get the system experiment-ready:

> *The dichroic has to be made and coated, the DM [deformable mirror] has to be coated, there is a set of beam expander optics which we've been waiting for since 2012 — they need to be delivered and coated, and we need a bunch of laser safety systems put in place, to use that Lockheed laser. And then, everything still has to be integrated, tested, and then we can perform the experiment.*

In October 2019 the Lockheed laser and the guide star adaptive optics setup were moved from where I had seen them a few months earlier in the AITC to the telescope laser lab,[476] but the systems were never fully integrated and despite renewed efforts in early 2021,[477] SERC never carried out the photon pressure manoeuvre. In the words of Travouillon when I interviewed him in June 2020, "we are kind of nearing the end. But 'end' is a bit like the horizon, you walk towards it but it's kind of, you're not quite getting closer to it". After a protracted wind-up period, SERC submitted its deregistration paperwork to ASIC (the Australian Securities and Investments Commission) in May 2021, and was formally deregistered in July 2021.[478] While ANU and EOS agreed to continue working towards the debris manoeuvre experiment after SERC ended, nobody I spoke to seemed particularly confident that it would ever happen.

For those working hands-on with SERC's instrumentation, this outcome was frustrating. Generally, the individuals I spoke to felt that the problem was not that EOS wanted to build their own laser (everyone genuinely liked both lasers and the EOS team) but they felt that EOS had gained significant benefits from the CRC, and that the leadership teams at ANU and SERC should have negotiated harder to gain more equal benefits on all sides. Such tightly interwoven technological challenges, financial, social, and organisational structures, and occasionally emotionally charged individual responses characterised much of SERC's working process, as this section has illustrated in some detail. In the following section, I draw out what a close analysis of SERC reveals about the process by which failure can be recontextualised and transformed into success.

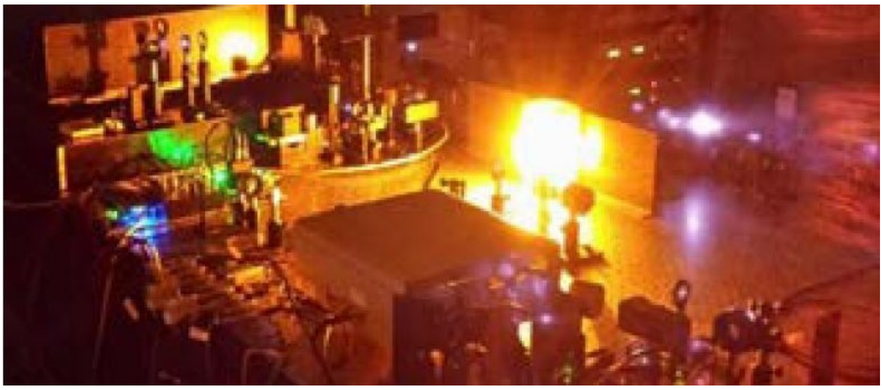

Figure 36 — The orange guide star laser being tested in the lab. Image from 2019 Annual Report.[479]

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[476] (2021). Final Report 31 March 2021, Space Environment Research Centre. p. 27.

[477] (2019). Annual Report 2018 - 2019, Space Environment Research Centre. p. 8.

[478] (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).

[479] (2019). Annual Report 2018 - 2019, Space Environment Research Centre. p. 29.

5.3 Political and legal context

It was really the poisoned chalice, that no one really want to take ownership of …
Because, like, I mean, that demonstration is hard.

Francis Bennet, SERC

What SERC never openly addressed is that, in addition to being technologically challenging, ADR is still legally and politically unfeasible. SERC's 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. It is not the aim of my research to address these matters in terms of international law generally, but it is worth touching on the key issues that might arise in relation to the sort of activity proposed by SERC. 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.[480]

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 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.[481] My empirical

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[480] 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.

[481] 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.

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".[482] 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".[483] 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.*[484]

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.[485] The gap between existing international space law and ADR technologies, which space lawyer P. J. Blount classifies as a *lacuna*,[486] 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.[487] In 2014 members of the Space Generation Advisory Council (SGAC), an international non-governmental, not-for-profit organisation which was formed in 1999 to

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Promoting Productive Cooperation Between Space Lawyers and Engineers. P. Anja Nakarada and T. Matteo. Hershey, PA, USA, IGI Global: 179-192. p. 180.

[482] 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.

[483] 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.

[484] Ibid. p. 428.

[485] 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.

[486] 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.

[487] Ibid. p. 182

support the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS), "through raising awareness and exchange of fresh ideas by youth",[488] 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.[489] They identified necessary actions such as agreement on a "shared definition of Space debris",[490] 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, the 10kW laser at the core of SERC's project, started life as an enhanced military tracking system within a war machine before 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".[491] The mission was deployed from the ISS and consisted of a "mothercraft" mini satellite and two CubeSats that became faux-debris,[492] on which a net and imaging / observation technology were tested.[493] The mothercraft also deployed a harpoon and a target, and included a dragsail.[494] The €15 million project was sponsored by €7 million from the European Commission with the "remainder self-sponsored by the partners".[495] 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").[496] Ultimately, the net successfully wrapped around one of the CubeSats but due to budget restrictions the net was

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[488] (2018, 2021). "About SGAC." Retrieved 07/04/21, from https://spacegeneration.org/about.

[489] 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

[490] Ibid. p. 200

[491] 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

[492] Ibid. p4

[493] Ibid. p4

[494] Ibid. p4

[495] Ibid. p5

[496] (2019). "Testing Technology to Clear Out Space Junk." RemoveDEBRIS Retrieved 09/04/21, from https://www.airbus.com/space/space-infrastructures/removedebris.html.

not tethered to the mothercraft, so could not be retrieved or deorbited.[497] The harpoon was also successfully deployed, striking the target "roughly the size of a table-tennis bat",[498] and unlike the net, was tethered to the mothercraft.[499]

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).[500] Astroscale is a private company registered in Japan and headquartered in Tokyo,[501] which aims to provide ADR as part of on-orbit servicing.[502] Like SERC and RemoveDEBRIS, Astroscale launched its own target satellite to act as faux-debris, rather than pick a piece of existing debris,[503] thereby avoiding associated legal and political issues. The project plans to use a magnetic system to dock with the target satellite.[504] 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.*[505]

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, currently doing the same thing Biddington did in his speech at Parliament House back in 2014, where the ambiguity of his language appeared to speak simultaneously to civil and military interests? Of course, the answer is complicated. My analysis of SERC has shown that there are a diverse range of institutions and individuals who are interested in ADR for an equally diverse range of reasons. But, as the SERC Achievement Snapshot said plainly, SERC's "sovereign designed and built laser", which was developed through cooperative research funded to a significant degree by the Australian Government and ultimately became the property of EOS, "has applications across both civilian and defence sectors".[506] Through projects like SERC, countries like Australia can engage in state-sponsored development of the workforce, supply chains, and sovereign capabilities that are themselves also 'dual-use'.

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[497] 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

[498] Ibid. p15

[499] Ibid. p16-17

[500] (2021). Astroscale Celebrates Successful Launch of ELSA-d, Astroscale.

[501] (2018). "Terms & Conditions." Retrieved 09/04/2021, from https://astroscale.com/terms-conditions/.

[502] (2018). "About Astroscale." Retrieved 09/04/2021, from https://astroscale.com/about-astroscale/about/.

[503] (2021). Astroscale Celebrates Successful Launch of ELSA-d, Astroscale.

[504] Ibid.

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

[506] (2021). Achievement Snapshot, Space Environment Research Centre.

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. As SERC encountered, 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.[507] 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.[508] He points out that although the US Government included ADR in their 2010 US National Space Policy,[509] 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".[510]

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,[511] 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.*[512]

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

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[507] 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.
[508] Ibid. p. 383-385.
[509] Ibid. p. 384.
[510] Ibid. p. 384-385.
[511] Ibid. p. 411.
[512] Ibid. p. 437.

technologies.[513] 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".[514] 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 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.

The other 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".[515] Challengingly for SERC, international space law does not distinguish between debris and functioning satellites: both are considered 'space objects'.[516] Any debris targeted by SERC would therefore fall 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".[517] 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.[518]

Liability is highly relevant for most ADR activities,[519] 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

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[513] 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.

[514] Ibid. p. 182

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

[516] Ibid. p.40

[517] (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.

[518] Freeland, S. (2021). Research Interview. HREC 2020/145. A. Handmer.

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

"authorization [sic] and continuing supervision" by States Parties of activities in outer space by all non-governmental entities.[520] 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.[521] 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",[522] 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.[523] 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 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 now, 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. 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.[524] 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

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[520] (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.

[521] Ibid. Article IX.

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

[523] Ibid. p. 42.

[524] Freeland, S. (2021). Research Interview. HREC 2020/145. A. Handmer.

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.[525] 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,[526] 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.

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 has established, through an empirical study of two projects that grappled with the problems of space debris and dual-use technologies, the ways in which Australia's space industry currently facilitates the abdication of moral and legal responsibility connected to international uses of space and space technology by constructing organisations that have the effect of temporarily structuring these problems out of existence. At the same time, SERC may be seen as a chapter in

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[525] 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 (2019). 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.

[526] 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.

Australia's state practice, which may in turn normalise the exploitation of ambiguities in international space law. Perhaps, in view of my analysis, it is worth considering whether the Australian Government's failure to form a national position on where the line should be drawn with respect to dual-use space technology, instead shifting responsibility onto institutions and individuals who structurally lack the authority to resolve ambiguities, should itself be considered an abrogation of moral responsibility.[527]

In the meantime, SERC's achievement was that it was able to balance these tensions and flourish within their bounds. SERC's partnership with Lockheed US allowed them 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.

5.4 Making a success of SERC

Something like this you can never say it was a success or failure, it was somewhere in between. It depends on who you're talking to.

Francis Bennet, SERC

To me as an outsider conducting a detailed study of SERC's work processes, the gap between how individual researchers explained to me the extent to which they saw their individual technological problems as insurmountable, and the way that senior leadership framed SERC's progress as resolutely 'on track', became increasingly evident. Every time I visited SERC, researchers shared their frustration that for years after it became obvious to them that the photon manoeuvre experiment could not occur within SERC's timeframe, they were being required to keep working to SERC's stated research deadlines. To them, SERC was a research project which had a technical goal: to conduct an on-sky laser experiment. On the other hand, senior members of SERC's research team consistently assured me that the experiment would take place. Even those members of SERC like Biddington, who must have been aware that given the technological challenges and delays it would not be possible to do the high power laser part of the demonstration, remained adamant that there was still the chance that SERC would complete the on-sky experiment in some form. Likewise, the Australian Government were presumably sufficiently confident that the on-sky experiment might happen to extend SERC to the end of 2020, which, as Gower confirmed for me, was "another 18 months beyond the end of the funding term". When I asked Gower whether the on-sky experiment could be done before this new deadline, he said "I would like to say yes, and that's why we're still running".

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[527] With a focus on individual constructions of moral agency, I return to the moral component of dual-use science and technology in Chapter 6.

In the face of technological limitations, the way that members of SERC spoke to me about ‘success’ changed. Gradually, ‘on-sky’ experiment came to stand for ‘laser guide star tracking’, as it was used in the Final Report, rather than ‘high power laser manoeuvre’. Descriptions of SERC’s main scientific goal shifted from being about moving debris to instead, as Travouillon put it to me, “to demonstrate that the principle functions”. He elaborated: “We are not trying to move objects; we are trying to demonstrate that they can be moved”. When we spoke, Biddington explained that SERC was really about developing capacity and capability in the Australian space sector, and that therefore the key success measure by which SERC should be judged a ‘success’ was its educational output, in which field he argued it had overachieved. Gower also highlighted this educational angle as being of importance, explaining that although SERC was originally “supposed to graduate 10 and enrol 24”, SERC would have graduated “18 or 19, and enrolled 26 students”, which “exceeded our education milestones”.

The SERC Achievements Snapshot, a document published in 2021 which presents an overview of the entire program, offers a useful source for understanding how SERC negotiated what some might see as a failure, in that SERC did not achieve the aim as stated in 2015 (“to manoeuvre space debris away from collisions using lasers on the earth”).[528] The document highlights the development of components and systems for adaptive optics, sensing, tracking, and the beam combining technology, and to the benefits of the new Space Object Catalogue, and orbit determination models developed through the research programs. It discusses the economic impact, and the enhanced industry collaboration that SERC promoted.[529] In addition, the document points to SERC’s outreach accomplishments, which totalled 19 television interviews, 145 print media articles and 29 radio interviews, alongside its academic achievements of 503 research publications and 1,027 citations.[530]

To Gower, who had taken on the role of SERC CEO at the time of our formal interview, SERC’s success should be measured more in the organisational outcomes of the project as a CRC than by its scientific achievements. For Gower, the elements he identifies as being ‘successful’ are not connected directly with his role, but stem from his view of the deeper purpose of the CRC. Gower explained to me that, as he saw it, SERC’s success was that it created IP and technology that could be commercialised by partners.

> *Will SERC have been a success? I think the short answer to that is yes. Absolutely. Our industry partners, so EOS for example, have new product lines, out of the work that has come out of SERC. So that’s brilliant. Optus will have access to an Australian conjunction threat warning system. So that’s a big success.*

Gower talked me through the process for dividing up IP, which mainly involved distinguishing between “background” and “foreground” IP. The agreement that SERC’s partners reached was that because the IP that partners had brought into the CRC outweighed the IP developed during the CRC’s operation, any additional “foreground” IP would “go back to the industry partner that is best placed to exploit it”. Gower explained that this system resulted in “people taking back what they’ve done”. Thus, EOS got all “background IP related to guide-star lasers, high power laser propagation, combining of high power lasers, background research related to conjunction and threat warning systems, [and] better tracking techniques”. Lockheed Martin received “data on performance of the entire system”. Optus Satellite Systems received IP related to the Conjunction and Threat Warning Systems. ANU and the other universities “get funded postdocs, they get funded research, and they

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[528] (2015). Annual Report 2014 - 2015, Space Environment Research Centre. p. 6.
[529] (2021). Achievement Snapshot, Space Environment Research Centre. pp. 3-4.
[530] Ibid. p. 11.

get whatever background research was done in their area of expertise". Specifically, ANU got all research related to adaptive optics, and RMIT received the modelling done on atmospheric density.

In addition to IP, cash and assets were divided between SERC's partners. Gower explained that dividing the cash was simple: "90% has got to go back to the Feds because they put [in] 90% of the cash". The remaining 10% went to the Academy of Sciences. Distribution of assets was more complicated because, as Gower noted, it required an accounting solution that "ensures that we're compliant with the Australian charities and non-profit commission and ASIC requirements". The solution reached and enacted by Gower and others in the management team was one that re-invigorated SERC's technologies to make them the foundations of new, ongoing, bilateral research agreements between partners.

> *What was said to our funding overlords, within the Department of Industry, is that even though SERC will end prematurely, our industry partners have undertaken, … "Our Partners" have undertaken to continue collaboration. And so EOS, through bilateral research agreements … So EOS and ANU, for example, will continue working on adaptive optics corrected satellite observations stuff, for example. So the work will continue, but it'll be through these arrangements. And those arrangements are actually underpinned in large part by hardware, or 'kit', if you like, that SERC has paid for.*

From an accounting standpoint, Gower confirmed my summation (based on my analysis of SERC's financial reports) that "all [SERC's] assets have been effectively written down to zero, over the course of this CRC". 'Writing down' an asset refers to adjusting its book value on financial records to a number lower than its original carrying value. In SERC's case, this was done primarily through impairment of assets, which involves re-assessing the 'recoverable amount' of an asset (e.g. how much could be recovered through selling it) and expensing the difference between that value and the value on the books. As a not-for-profit entity, SERC used the depreciated replacement cost as the value in use, expensing the difference between this depreciated replacement cost and the carrying value on SERC's income statement.[531] It was through this mechanism that, in 2018, the value of SERC-developed technology ("Research Equipment"), including the laser, adaptive optics, and guide star laser system, was written down ('impaired') by approximately half a million dollars.[532]

Once the official value of the technology had been reduced on paper, SERC then had to find a way to transfer that technology to institutions who would be able to use it. As Gower put it, "what do we do with them then? Do you throw them in the dumpster, or put them on eBay? You do much better to actually … for those assets to go to our industry partners, so they can continue collaboration". The difficulty SERC encountered was that even though the assets were worth far less on paper after 2018 than they had been worth in, say, 2017, it was still not lawful for participants to benefit from the wind down or the shutdown of SERC, because SERC was a registered charity. But as Gower explained, it was still "perfectly legal" to "'sell' assets for services", exchanging them for a further period of 'in-kind' contributions from partners during SERC's protracted wind-up period. Between mid-2019 and the end of 2020, "universities continued to put in all their in-kind stuff, in exchange for the assets, identified assets that they could use", and agreed "after that period to continue collaborations". Gower pointed out to me that apart from being sound from an accounting standpoint and compliant with the ACNC (Australian Charities and Not-for-profits Commission) and

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[531] (2018). Annual Report 2017 - 2018, Space Environment Research Centre. p. 13.

[532] (2018). Financial Report for the period 1 July 2017 to 30 June 2018. CRC for Space Environment Management managed by the Space Environment Research Centre Limited (SERC). Australian Charities and Not-for-profits Commission p. 18.

ASIC, “the feds love” this solution because it ensured “continued collaboration between our industry partners”. Among the assets identified as those that partners could claim in exchange for services were the four laser amplifiers that were used to build SERC’s 8kW high power laser. These were transferred to EOS along with the beam combiner technology because, as Gower put it, “they do lots of laser work, would be the way to say it”.

Among everyone I interviewed, the consensus was that whether or not the division of cash, assets, and IP was fair, the solution was mutually beneficial. As Bennet explained, after detailing the division of IP and assets (EOS got the high power laser and guide star laser and associated IP, and ANU took the IP and hardware for the laser launch telescope and the adaptive optics systems):

> *… basically, EOS got the hardware and IP that they really cared about, ANU got the hardware and IP that we really cared about. I think in the end that was reasonable enough. But we don’t actually know how much all the lasers cost, we don’t know how much FTE went into it, we don’t know how much all of our staff cost or the FTE that went into it. So, I don’t know whether it was a fair division or not … But does it really matter? We both got what we wanted out of it, so who cares?*

Even though the decision to spend time, funding, and capability on developing a second high power laser (and associated IP) that would eventually benefit EOS, instead of integrating the Lockheed laser, had flow-on effects for the rest of SERC’s research programs, the individuals from ANU I spoke to seemed broadly happy with the outcome, citing the many other benefits SERC had had for their strategic goals and for the ongoing relationship between ANU and EOS. Colless, who viewed SERC as “one of the government’s sporadic efforts to take the powerhouse that we’ve got in the universities, and in particular in astronomy, and turn it to some good in industry” saw SERC as overall being successful because it contributed to ANU’s strategic goals, one of which was to become more involved in Australia’s space industry. He cited ANU’s new Institute for Space (‘InSpace’), led by Anna Moore (who had, almost two decades previously, travelled to Dome C with Storey) as an example of a positive outcome for ANU that had been “partly built on our success with the CRC”. Travouillon felt that the “industry side is completely irrelevant” to ANU’s research interests, and that for his team, it was “a plain research interest”, about “getting know-how and knowledge”, which they were able to achieve.

Many of the individuals who worked on SERC advanced their careers as a result of their work with the CRC. Bennet was able to pivot his laser expertise to focus more on laser communications, which he explained was “a very hot topic”. With “a lot of funding available for that area”, Bennet explained that many members of his SERC team had also moved across with him. Some also transitioned out of academia and into industry. For example, after completing his PhD with SERC, O’Leary got a position at EOS as a ‘Research Fellow’.[533] James Bennett, who had led Research Program 3, became Head of Technology Development for EOS Space Systems.[534] Ball, the CEO of SERC, was recruited into the role of Regional Director for Lockheed Martin Space, Australia and New Zealand.[535]

In this chapter I have analysed the components of SERC’s experimental setup, describing in detail the technological complications that arose and that led to SERC’s failure to demonstrate the remote

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[533] O'Leary, J. (2021). "Joseph O'Leary."   Retrieved 14/05/21, from https://www.linkedin.com/in/joseph-o-leary-194a5975/?originalSubdomain=au.

[534] Bennett, J. (2021). "James Bennett."   Retrieved 14/05/2021, from https://www.linkedin.com/in/james-bennett-754470b9/.

[535] Ball, D. (2021). "David Ball."   Retrieved 14/05/21, from https://www.linkedin.com/in/david-ball-08542b/?originalSubdomain=au.

debris manoeuvre. I showed how one such failure (the M1 satellite) was actively framed as a success. I examined how technological problems were compounded, caused, or in some cases solved, through SERC's official and unofficial structures, as established in Chapter 4. I also showed, through juxtaposing different perspectives, how individuals saw themselves fitting within the broader research context of SERC, highlighting the importance of SERC's social structures. I then outlined the legal and political issues that SERC avoided by not carrying out the debris-manoeuvre, and examined the gaps and complications that dual-use technologies present for existing international legal frameworks. Finally, I detailed the ways in which SERC was practically and administratively disassembled, outlining the process by which cash, IP, and assets were divided between participants. In the last part of this chapter, I demonstrated how those with the desire and power to do so negotiated the terms of 'failure' unchallenged, making a success of SERC.

Chapter 6: Conclusion

Figure 37 - A penguin considers a container full of explosives.[536]

6.1 What to make of dual-use?

> *A whole bunch of people who won't work for the military are happy to work on dual use stuff.*
>
> **Matthew Colless, PILOT & SERC**

Every person I spoke to about SERC was emphatic on the point that SERC was a civil science project, with potential to benefit commercial uses of space. And in one very obvious sense, SERC *was* entirely civil in character; the first iteration of what would become SERC, a CRC proposal which contained classified elements, was rejected for CRC funding.[537] On the other hand, the core of the experiment, the laser whose beam would exert photon pressure on an object, was developed for military uses. Search the internet for the Lockheed ADAM system, and you'll find videos of the same class of IPG 10kW laser that sat in a packing crate at Mount Stromlo for years being used to 'neutralise' rockets, boats, and vehicles, in slow-motion demonstrations. While it was at SERC, the IPG laser was civil technology. After SERC finished its activities, the IPG laser was shipped back to Lockheed Martin, instantly becoming military technology once more. Another major component, the guide star laser, developed through SERC's activities, has since became the property of EOS, where its "applications across both civilian and defence sectors" will be harnessed through EOS's commercial activities.[538] Depending on the time, the context, the individuals involved, and the stated reason, SERC is living proof that precisely the same 'dual-use' object may be reframed and classed as civil, military, commercial, or some combination of the above, and that the way that object is classified has real implications. What is it that makes a laser on one day an 'instrument of amoral science' or of social good, and on another day, in the same hands, a weapon? Analysis of the technology can only get us

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[536] Photo by David Neilson, published in Neilson, D., Alexander, K. (2012). Southern Light: Images from Antarctica, Snowgum Press.

[537] Biddington, B. (2020). Research Interview 1 of 2. HREC 2020/145. A. Handmer.

[538] (2021). Achievement Snapshot, Space Environment Research Centre. p. 10.

so far; it's hard to improve on the elegant simplicity with which Gower said to me, "a knife has a military use as well as for dicing apples".

Understanding and, arguably, instrumentalising the slipperiness of such designations, the people who created and operated SERC were careful about what words and images they used to describe its activities. Biddington explained that the Board and management of SERC were deliberate in positioning SERC as being entirely civil in its operations. Gower, who headed up the management and publicity for SERC for much of its operation, spoke about "managing the message". Although SERC was a civil, unclassified project, it utilised dual-use technology, and Gower explained that he was "very careful" about the media he shared about SERC, to avoid the risk of it being construed as "a wolf in sheep's clothing". At the same time, while maintaining that SERC had "absolutely no interest in using [the technology] in any military sense, at all", Gower was pragmatic about the commercial interests of SERC's industry partners. In his view, once SERC was finished, "what they do with it, that's their business".

It seems self-evident to point out that SERC's technology and research was dual-use, and reasonably straightforward to claim that SERC itself, as an organisation, was also dual-use. It is not too tenuous to say that the institutions like ANU RSAA that participated in SERC's CRC structure were also, in a sense, dual-use — but what does the construction and existence of such an institutional structure entail for the individuals working within it, as technologists and researchers in an awkwardly hyphenated dual-use zone? When Forge writes about dual-use and scientific morality, he misses that in some cases the funding, research, and organisational structures and the social constructions of reality within which individuals operate seem deliberately arranged if not entirely to obscure an individual's ability to see the implications of their research, then to sideline the need for consideration of such individual moral agency. It would be simpler for the reader if the story I told about SERC depicted a cynical exercise in tricking a nation into spending public funds to gift a sparkling array of cutting-edge weaponry to a private company that sells the tools of war, but that is precisely the sort of temptingly simple narrative that does not do justice to what is a deeply complex and multifaceted issue.

Through the careful illustration of technological, social, financial, and organisational processes, I have tried instead to show SERC as it appeared to me: a collection of brilliant people coming to work every day to try to solve problems, enabled through organisational, research, financial and social structures to be oblivious to the need to consider any moral or practical implications of their work. From budgets to reporting lines to the technology itself, SERC ran on opacity; a series of filters, lenses, and mirrors set up in just the right arrangement to let only the vital information through, and even then, not without concerted tinkering on the part of the research staff. There was underlying uncertainty as to whether it was possible to carry out the on-sky experiment at all, or within the time frames, or the budget, or the legal parameters. SERC's dysfunctional opacity facilitated the construction — at least when prompted by my questions — of as many narratives of ethics as there were individuals. Through the CRC model, each person working with SERC was able to shape their involvement such that they never had to contemplate or cross their own moral line. In fact, as Colless explained to me, this was part of the appeal of conducting SERC's research through a CRC structure: "a whole bunch of people who won't work for the military are happy to work on dual-use stuff".

So in these concluding remarks I return to the initial motivation for my research, the tensions apparent in Will Saunders' 'NO WAR' manifesto. I return to the human side, and analyse how those working at and with SERC conceptualised and rationalised their activities. To complement the sort of outside-in approach that Forge and others have employed, I present an empirical study of how those working at the fuzzy 'dual-use' boundaries of the military-civil hyphen see themselves. If I conclude this thesis by describing the way that research participants in my study of both PILOT and SERC communicated their understanding of where they fit in the civil-military divide, it is in order to better understand not only how they thought about their activities, but also to make clear the way that the financial, social, and governance structure of research institutions produces conceptual spaces within which individuals construe themselves as moral agents, and which prefigure understandings of the room for moral choices.

6.2 Science as an amoral good? The cases of SERC and PILOT

You know it goes back and forth and back and forth, because astronomers have very big challenging problems and we have got really smart people working on them. We often come up with new techniques and abilities that are then taken back by industry, or by the military and redeveloped for their own purposes.

Matthew Colless, PILOT & SERC

One of the strongest arguments that emerged from my conversations, informal and formal, with individuals connected to SERC and PILOT, was that everything they were doing had probably already done before in a classified context. Bennet pointed out to me that if the individuals who founded SERC had wanted to do fresh military research, they wouldn't have chosen a CRC structure, or the Department of Industry, Science, Energy and Resources. There are other, easier ways of accessing funding for defence research (i.e. through the Department of Defence) that don't involve having experimental setups published freely in scientific journals. In an abstract sense, Travouillon acknowledged that it was important to consider how his research could be used, explaining that when speaking about results or publishing "you maybe give some other people ideas on how to use this technology in a different way, a brainwave, but which you have no way of controlling. So your research does have an impact that you should consider, potentially. You know, 'am I doing the right thing by publishing this?'"

But in practical terms, as a scientist benefiting from the transfer of this technology into the civil research space, Travouillon explained that he simply didn't know, and couldn't know, whether the use of such high power lasers and associated adaptive optics technology had already been demonstrated in a classified context. He was confident that high power lasers that would theoretically be capable of causing damage to or 'shooting down' satellites "already exist", adding "Defence has tons of them". As to whether they might be used for this purpose — "has it been used this way yet? I don't know … and I bet you I will never know" — Travouillon was agnostic, although he noted that such activity was "definitely the less ethical use for them". In his mind, "I have literally no idea. I think there's a really clear division between civil research and defence. We really are … it is, it's completely opaque to us". Given that astronomers gained access to adaptive optics expertise in the 1980s through the declassification of military research on the subject (championed by physicist Townes) this perspective from Travouillon is perhaps unsurprising.[539] More significantly, through his PhD supervisor Storey, who did his postdoctoral research under Townes, Travouillon has a direct link to this event and the significance it had for his field of academic research.

When I interviewed Saunders in mid-2020, I asked him about his views on the relationship between science and politics. As previously noted, despite developing the design for PILOT's debris camera,

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[539] Finkbeiner, A. (2006). The Jasons: The Secret History of Science's Postwar Elite, Penguin Publishing Group.; Finkbeiner, A. (2015). Charles Hard Townes Made Things Happen. The Last Word On Nothing, Independent.

Saunders was entirely unaware of any behind-the-scenes dual-use discussions, but I was nevertheless curious to know how a scientist who had gone through the legal system in a very public way and become, in some sense, a political figure in his own right following his ascent of a national icon, thought about his own place within a political milieu — or indeed, if he thought about it at all. While Saunders pointed out that he would need "several weeks to think how [the relationship between politics and science] should be", he felt that "clearly they are connected. Clearly there has to be some connection. Clearly those collections — connections — can be misused in both senses". But when it came to understanding the nature of those connections, Saunders drew a firm distinction on the direction of flow of expertise. His clear view was that information flowed from the military to civil science, and that this relationship was "entirely one way". He added, "I don't think we [astronomers] ever did anything that was useful to the military, that I knew about". To Saunders, the use of technology for civil science that may have once been developed for military purposes was not a moral issue, because he assumes that the military already has far greater capability than he does, and therefore that no research done by him could benefit the military. He, too, gave the example of adaptive optics, adding "I assume they've got better things by now". In Saunders' view, "astronomers would get the toys that the military were no longer interested in". To illustrate his point, Saunders told me about how he "heard it said that the first infrared detector chip had 'tank buster' written on it in tiny, microscopic letters".

On the question of the connection between science and politics, Saunders eventually referred the issue to Colless, saying "he has an answer for most things". Colless duly delivered, telling me that "all science is politics. It always is". To Colless, "hoping to separate science from politics is … you know … dreamland", but he felt that it was nonetheless possible to "find out those pure objective facts, because they do exist, despite what every relativist in the Philosophy of Science may tell you". Describing himself as one of those "on the frontlines of science", Colless explained to me that "all this stuff we do is intended to try and get at some of that, you know, ideal truth". He added: "it's our imperfections that limit us, not the fact that there is no truth". Thus, in contrast to both Saunders' view that the exchange between military science and civil science only flows one way (and civil scientists are therefore not morally responsible for military applications of knowledge), and Travouillon's additional view that there is an opacity between civil and military science, Colless characterised the relationship between classified and unclassified, military and civil science as being an exchange.

In his leadership role for an institution, Colless explained that collaboration was, as part of "the stuff we do", an existential necessity for scientific institutions, and that part of collaborating involved sharing information in both directions. He described this flow of information as "back and forth and back and forth", explaining that in astronomy, researchers "often come up with new techniques and abilities that are then taken back by industry, or by the military and redeveloped for their own purposes". Colless also spoke to me about adaptive optics, but unlike Travouillon and Saunders who presented it as a one-time moment of declassification, Colless framed it as an ongoing exchange, with benefits for both sides. He explained that the declassification of adaptive optics research allowed astronomers to "say to funding agencies 'hey look, it actually does work, the military guys have shown that it can be done'", which accelerated civil research in the field. Likewise, he told me that astronomers have "now started running with it, doing things with it, that in fact the military people hadn't been interested in, or hadn't realised were interesting, and so on, and now they're again taking it back again".

This framing is important, because Colless went on to explicitly position SERC as "an obvious example of precisely that back-and-forth and back-and-forth, between different areas of interest".

Unlike Travouillon who pointed to the opacity that he encountered between military and civil uses of SERC's technologies, Colless, sitting at SERC's Board level, asserted that "information isn't siloed or hidden. Almost everything is in fact known and shared". It just so happened that "the techniques that we'd picked up from military and then developed for astronomy, now turn out to be interesting for space situational awareness, for tracking space junk, and so on", and SERC enabled that "interplay". Exchanges between military and civil astronomy research that, in PILOT's case, had previously been unspoken had, in the years between PILOT and SERC, been built into corporate structures. Colless felt that there was no practical way in which science and politics could ever be independent for one another, so the best and most "effective environment" came out of cooperation between the two towards scientific ends. He explained:

> *… on the military side, you know, we are now doing, as astronomers, more work for defence then we would ever have done in the past. And we're able to do that in a very transparent, straightforward way. They are happy — we're not doing secret contracts or anything for them, they're just funding us to develop technology that they're interested in for their own applications but which we can use and we're free to publish as well. And so that's a much more healthy relationship, as well.*

Of course, not every astronomer is happy to work on military contracts. Among those I interviewed, the perspectives and moral codes I encountered were as different and nuanced as the individuals themselves. But, as Colless went on to explain, there is a larger cohort of scientists who are comfortable working on something that is dual-use than those who would sign up to work directly for a military institution. As he put it, "developing open research is good because they can then get a much bigger group of people working on it. A whole bunch of people who won't work for the military are happy to work on dual-use stuff". Thus, while Travouillon and Saunders might have been confident in their view that knowledge and expertise only flows one way, and the military already had all the techniques and technologies they were developing as civil astronomers, whether working on PILOT or SERC, Colless raised a compelling counterpoint: that structures like SERC which conduct dual-use research "just means that they [military entities] just get access to a bigger pool of people, with additional funding sources and other streams of information that they wouldn't otherwise have". In the next section, I illustrate how SERC's structures were experienced by early-career researchers as they told it to me.

6.3 Moral responsibility distributed is moral responsibility solved?

… if everybody doesn't feel responsible, at their own small-scale, and then you put all these things together, we could accidentally make a super weapon, and then nobody feels guilty.

Jesse Cranney, SERC

SERC was a sprawling and diverse organisation, whose members worked in siloed teams in a variety of locations, navigating complicated governance and funding mechanisms with varying degrees of organisational oversight. Individual experience of the researchers I spoke to and their perspective on the moral dimensions of their work differed considerably. Perhaps, as Colless suggested, institutional arrangements like SERC structured the exchange of knowledge between civil and military science in ways that were efficient and cost-effective for both sides. However, as SERC-PhD-student Cranney explained to me, they also made it effectively impossible for any one individual to be able to see the whole picture, making it difficult to perform the sort of foresight analysis advocated by John Forge.[540] This effect was particularly true for the early-career researchers I spoke to; the higher up in SERC's organisation, the more oversight individuals had.

Working on control theory which improved the performance of the adaptive optics loop, Cranney explained that he was aware that "there's a nonzero amount of military interest in what the SERC project is". He participated in the sort of foresight Forge discusses, describing to me how the presence of "kind of defence related companies" at SERC events prompted him to consider whether his research, or the "big crazy powerful lasers" he knew SERC was developing, could be used "in the wrong way". He continued: "you know, your mind wanders, and you think 'okay, if I wanted to, could I turn what we're building into some kind of weapon?'" Cranney made it clear to me that he is "personally, like, incredibly pacifistic", and that it was important to him, when joining SERC (although he "never got anything in writing, obviously") that "there was kind of this idea that, anything, would only be used for satellite tracking and … non-defence purposes". Cranney also identified the distribution, "publicly", of SERC's research as a factor which influenced his feelings about the ethics of the activities being undertaken, although he was unsure why he felt that this aspect of SERC mattered to him. Ultimately, he considered his own PhD work as being distanced in some way from possible military uses because of its theoretical nature and specific application to the technical problem — atmospheric turbulence prediction — he was solving.

Similarly, O'Leary, working on mathematical theory for his PhD work, felt that there was never "any sort of issue with ethics", because his work was distant from the possible applications. He specifically identified that although mathematics "lays the foundation" for practical applications, "it almost feels like it doesn't belong to it". He went on to explain that he saw mathematics as "slightly detached, because there is a middle person to go through", translating theory into practice. Speaking specifically about his work at SERC, O'Leary told me "I haven't had to make any decisions, which are based on morals or ethics". Le May explained to me that she saw SERC as a valuable tool through which the sustainability of space could be improved, and equity of access to space for a variety of "human-based problems" and environmental causes. However, like O'Leary and Cranney, she also felt detached from ethical questions related to SERC-developed technology because, in her research on debris modelling, she "wasn't involved with the laser stuff so much".

During the course of our discussion it occurred to Cranney, perhaps for the first time, that his mathematical modelling could perhaps be combined with other aspects of SERC's research, and that it was "not actually so far-fetched" to consider that "the same technology could be … could be applied to — do something destructive". He described this moment of realisation as prompting a "little existential crisis". Cranney went on to unpack why it was that he had only, up to this specific moment in our interview, considered the possible implications of his research in isolation, and had not considered how it might combine with everyone else's research. He explained, "you kind of joke around with the supervisors about it — and, yeah, the other students". According to Cranney, "everyone's got the same kind of sentiment", recognising that "there's the same ingredients in there, for something potentially dangerous", but that "in the configuration that … we're exposed to, it certainly doesn't seem like a very useful weapon".

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[540] Forge, J. (2019). The Morality of Weapons Research: Why it is Wrong to Design Weapons. Cham, Springer International Publishing.; Forge, J. (2010). "A Note on the Definition of "Dual Use"." Science and Engineering Ethics **16**(1): 111-118.

> *You've got the problem of many hands. Like if everybody doesn't feel responsible, at their own small-scale, and then you put all these things together, we could accidentally make a super weapon, and then nobody feels guilty.*

Following this realisation, as our conversation continued, Cranney considered all the parts together, and decided that in the end it would be "shocking if they tried to turn this into a weapon", citing the cost, the upkeep, the personnel requirements, and the fact that it was "not super robust". Nonetheless, what became increasingly apparent throughout my study of SERC was that its disparate organisational structure had the effect, intended or otherwise, of ensuring that nobody thought too carefully about the moral implications of their work.

6.4 Technology has no morals?

I think the truth of the matter is that technology is … technology has no morals.

John Storey, PILOT

Most people I interviewed did not feel quite as strongly as Colless that the value of scientific research in and of itself outweighs the circumstances in which the science is done, by whom, and with what funding. Saunders, for example, said that he considered astronomy to be, in some ways, a luxury. It was hard for Saunders to justify expenditure of "Christ, a billion dollars" on a telescope when the world is faced with all manner of existential threats and social injustices. In counterpoint to Colless's stirring words about the purity of objective facts, and the platonic idealism of the "truth" of the "objective universe", Saunders would only go so far as to say that "a society that does no research would be a very sad thing", and that it "would really be a shame, if there was no sense of inquiry about nature, about the universe". But at the same time, Saunders explained that there was a "paradox" of government spending that meant that the money spent on science was not the same as the money that might be spent on social services — they came out of different "pots". He invoked the military-industrial-complex, telling me that "the reason that governments invest in space and, for that matter, arms, is the pump priming for the economy that it provides", and that spending on a "high-tech hole in the ground like a particle accelerator or a telescope" is "less bad than the military use". To Saunders, it is "important to realise; that until the politics changes, they're not the same pots of money".

Storey, the only person I spoke to about PILOT (apart from Biddington) who was consciously aware that the debris camera was part of a dual-use project, also expressed a view in line with Saunders': until the politics changes, the money that funds telescopes isn't the same money that funds social services. He explained to me that he'd been "kind of on the fringes, of military stuff, for most of my career". Storey drew a distinction between his pragmatic perspective ("if the military is spending money on you, then at least they're not spending it on bombs") and his inner "idealist" ("I wouldn't want to do anything that was … was helping the military to … position themselves to be more aggressive"). Speaking about PILOT's dual-use element, Storey explained that Biddington ("quite a persuasive person") talked him into the view that open surveillance of the kind proposed for PILOT was "stabilising", and non-aggressive. He drew an analogy between PILOT and Antarctica's "network" of seismograph facilities that are used to detect both earthquakes and "nuclear explosions".

> *And so you've got a facility that does fundamental science, it does practical, useful scientific monitoring, and it's also doing military … military surveillance. I guess I saw PILOT's satellite debris capability, as being exactly analogous to that, and that made me feel comfortable.*

While their wording is similar, Storey and Saunders make two subtly different points. Saunders' point is that money spent on astronomy is more likely to come out of a national security budget than a healthcare budget, but that this distinction doesn't exonerate scientists from questions of moral responsibility because they are part of a political system that results in this distribution of funding to begin with. Storey's argument begins at the same point — money spent on astronomy is more likely to come out of a national security budget than a healthcare budget — but his conclusion is that scientists have a responsibility to consider not just where their funding is coming from, but also what knowledge and technology they are choosing to develop with that funding. For Storey, the intent may be to use the money to conduct the sort of research that Colless values — research that enhances human knowledge about the universe — but the individual scientist must be aware that this same research could have military applications. Overall, Storey felt that the sort of 'extra science case' dual-use bolt-on that PILOT had contemplated was morally distinct from the kind of research that SERC did, because, in his words, "I don't think it takes an Einstein to see that if you can do that to [manoeuvre] a piece of space junk, you can do it to something that somebody doesn't consider to be junk".

Bennet likewise made a distinction between use of technology for intelligence purposes "which are necessary for every nation to do" and use of that same technology for lethal military operations, explaining "I wouldn't want to go into manufacturing bombs, however optical systems are optical systems. If it just happens to be called dual-use, okay". In contrast to his old PhD supervisor Storey, Travouillon felt that there was not a clear difference between observation and action when it came to the ethics of SERC's technology. For him, the pertinent question was whether the technology was being used "to defend yourself" (for example, to prevent foreign surveillance satellites observing activities, something that can be technologically achieved through activities like laser dazzling) or "to affect other people's technology". Similarly, Gower told me he was "personally not philosophically adverse to them creating things that protect us. It becomes an issue when they become offensive". To Cranney, on the other hand, at an earlier stage of his career, the difference came down to the direction in which the telescope was pointed. While he wasn't sure why he drew a distinction, he felt "completely comfortable with surveilling satellites" from earth, but not with using satellites to surveil Earth-based targets. Cranney acknowledged that his sense that there was a difference between the two was a "contradiction", and felt that perhaps he had to "somehow, resolve that internally" — but not until he had submitted his PhD thesis.

6.5 If no-one is responsible, is everyone responsible?

If they wanted people to do more civilian research, they should pump up the civilian research funds.

Francis Bennet, SERC

The other important element that arises from Saunders', Storey's, and Colless's positions is the prioritised place that funding has in determining the speed and direction of research. They consider science to be connected with politics, or in Colless's case, science to *be* politics, because politics is the lever by which funding is distributed. A political priority is, by virtue of the mechanisms by which science is publicly funded in Australia, a research priority. The more important the issue is to the state, the more funding will be allocated to solving that issue. It logically follows that scientific research which pertains, or could pertain, to matters of national security (e.g. SERC) is more likely to receive funding than scientific research that comes up short in a return-on-investment analysis (e.g. PILOT). Of course, there is also the matter of public will, and it is here that the team behind SERC benefited from being part of (or perhaps consciously constructing) what Bennet called a “national story”. Projects like SERC and PILOT are so expensive that they need government backing to be built. And, as Colless explained to me, “any time you are dealing with people and money there are ethical issues. And so to pretend that science can be divorced from people and money is truly to live in cloud cuckoo land”.

As someone with a deeper understanding of SERC’s funding situation than most, Gower felt that even though the civil space industry in Australia is growing, space activities in Australia are influenced heavily by Defence, which “absolutely dwarfs civilian applications”. In SERC’s operations, Gower sat at precisely the interface between politics and science: reporting on SERC’s progress to “the feds”, overseeing the distribution of funds to the researchers, and actively managing SERC’s public profile. He explained that Australia’s recently formed Space Agency, although “absolutely civilian” is “always bumping up against Defence”. To Gower, the key issue is that “you need lots of money to get up there, and Defence have lots of money”. Bennet, working on the science side of the science-politics interplay, pointed out explicitly that the way funding is allocated, to astronomy research in particular, incentivises scientists to pursue projects with military applications.

> *Defence is very well funded. I think the government is kind of pushing people in that direction. If they wanted people to do more civilian research, they should pump up the civilian research funds.*

However much funding is currently flowing from Australia’s Department of Defence into space activities, and however that compares with the amount of funding that was flowing through 20 years ago (noting that the opacity of classified programs makes it difficult to assess), what can be seen with clarity is the shift between the subtle way that PILOT approached dual-use elements of its design, and the structured approach the SERC took. I asked Jon Lawrence how it was that a relationship between astronomy and military interests went from being an unspoken understanding to an advertising tool. He suggested that it came down to funding, explaining that “there’s a realisation that there’s other funding routes and opportunities if you’re prepared to step outside the, you know, what the focus is, perhaps?” Lawrence went on to note that if you do ‘step outside the focus’, “then you have to acknowledge” where the money came from.

The value in studying projects like PILOT and SERC is in tracing, in detail, the ways in which people working within social, financial, political, legal, and organisational structures conceptualise their relation to ethical and practical questions. Such an analysis moves beyond questions about *what* senior figures like Colless, Storey, Gower, Bennet, Travouillon or others thought about their moral responsibilities, and highlights instead *how* financial, social, and governance structures shape the spaces within which individuals make moral choices: by illustrating how PILOT left dual-use questions unspoken, and how SERC structured the unspoken exchange between military and civil science in such a way that the individuals who participated in my research saw their activities as distinct from issues of moral responsibility, my research addresses more complex questions: It explains why Saunders didn’t notice that he was designing a dual-use instrument for PILOT, why Cranney, developing software for an adaptive optics system, hadn’t considered how his part fitted into the whole, and, importantly, it reveals how Australian space science currently engages with the development of dual-use technology. While my research is not normative in aim, it begins a sentence by providing two interlinked empirical studies about the current treatment of dual-use technology in Australian space science, in the hope that others might complete it.

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