ACIL ALLEN

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Report to Department of Industry, Science and Resources

Evaluation of the Access to World Leading Astronomy Infrastructure (AWLAI) program

Final report

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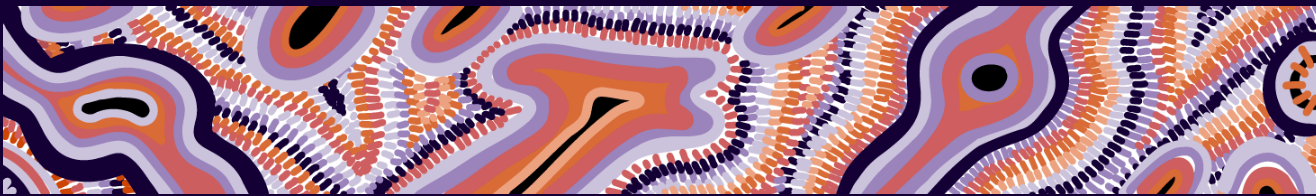
ACIL Allen acknowledges Aboriginal and Torres Strait Islander peoples as the Traditional Custodians of the land and its waters. We pay our respects to Elders, past and present, and to the youth, for the future. We extend this to all Aboriginal and Torres Strait Islander peoples reading this report.



Goomup, by Jarni McGuire

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Glossary

AAL	Astronomy Australia Limited
AAO	Australian Astronomical Observatory
AAT	Anglo Australian Telescope
ACAMAR	Australia-China Consortium for Astrophysical Research
AESOP	The Australian-European Southern Observatory Positioner (AESOP) is the fibre positioner unit for the 4MOST instrument.
AITC	Advanced Instrumentation and Technology Centre
ALMA	Atacama Large Millimetre/submillimeter Array
ANU	Australian National University
ASA	Astronomical Society of Australia
ASKAP	Australian Square Kilometre Array Pathfinder
Astralis	The Astralis Instrumentation Consortium - develops, builds, and tests custom, cutting-edge solutions to astronomical challenges.
ASTRO 3D	Centre of Excellence for All Sky Astrophysics in 3 Dimensions
ATNF	Australia Telescope National Facility
AUKUS	The trilateral security partnership for the Indo-Pacific region between Australia, the United Kingdom, and the United States.
AWLAI	Access to World Leading Astronomy Infrastructure
BlueMUSE	An optical seeing-limited, blue-optimised, medium spectral resolution, panoramic integral-field-spectrograph.
Coordinating Group	Australia-ESO Coordinating Group
CSIRO	Commonwealth Scientific and Industrial Research Organisation
Decadal Plan	Decadal Plan for Australian Astronomy 2016-25
(the) Department	Department of Industry, Science and Resources
ELT	Extremely Large Telescope
ESO	European Southern Observatory

ESO-SP	The Australia-ESO-Strategic Partnership Arrangement
ESOStats	A database of Australian-led ESO proposals and publications
GMT	Giant Magellan Telescope
HARMONI	The High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph (HARMONI) is an adaptive optics assisted, visible and near-infrared integral field spectrograph being built for the ELT.
ICRAR	International Centre for Radio Astronomy Research
ILO	Industry Liaison Officer
Keck	The W. M. Keck Observatory is an astronomical observatory with 2 telescopes in Hawaii.
LPO	La Silla and Paranal Observatories
MAOAC	Maintaining Australia's Optical Astronomy Capability
MAVIS	The MCAO Assisted Visible Imager and Spectrograph (MAVIS) is an instrument being built for the ESO's VLT.
MUSE	The Multi Unit Spectroscopic Explorer (MUSE) is a second-generation instrument in development for the VLT.
MWA	Murchison Widefield Array
NTT	New Technology Telescope
OPC	ESO's Observing Programme Committee
OzGrav	Centre of Excellence for Gravitational Wave Discovery
(the) Roadmap	National Research Infrastructure Roadmap
SKA	Square Kilometre Array
SSO	Siding Spring Observatory
STEM	Science, technology, engineering and mathematics (education priorities)
Subaru	Subaru is an 8.2-metre optical-infrared telescope located in Hawaii and operated by the National Astronomical Observatory of Japan.
USyd	University of Sydney
VISTA	Visible and Infrared Survey Telescope for Astronomy
VLT	Very Large Telescope
VLTI	Very Large Telescope Interferometer
VST	VLT Survey Telescope
XSHOOTER	XSHOOTER is the first of the second-generation instruments of the VLT.
4MOST	AESOP 4-metre Multi-Object Spectrograph Telescope
μm	micrometre

Executive summary

Introduction

Australia has a strong record of research and scientific capability in astronomy. As stated in the Decadal Plan for Australian Astronomy 2016-25 (Decadal Plan):

> *Over the past decade, Australian astronomers have achieved major international breakthroughs in optical/infrared and radio astronomy and in theoretical astrophysics.*[1]

The Australian government's investment in domestic astronomy infrastructure and participation in international collaboration projects, supports Australian astronomers with access to large and complex telescopes. This helps facilitate Australian astronomers' discoveries, and more broadly, the development of Australia's capabilities in science, advanced technology development, advanced manufacturing, and computation and data science. The astronomy sector also assists in maintaining Australia's broader scientific and technological capability. It is part of the research and innovation ecosystem in Australia, which provides a wide range of economic, environmental, and social spill-over benefits to the Australian community.

As part of the Australian Government's investment in optical astronomy, the 2017-18 Budget included funding for the Maintaining Australia's Optical Astronomy Capability (MAOAC) budget measure. The *Access to World Leading Astronomy Infrastructure* (AWLAI) program was created specifically to implement this budget measure. AWLAI is administered by the Department of Industry, Science and Resources (the Department).

AWLAI enabled Australia to establish a Strategic Partnership with the European Southern Observatory (ESO), known as the Australia-ESO-Strategic Partnership Arrangement (ESO-SP), including access to the La Silla and Paranal Observatories (LPO) for 10 years to 1 January 2028. The budget provided funding of $129.2 million over 10 years.[2] This included a February 2022 amendment to expand Australia's access to ESO facilities and enable tendering for ESO contracts.

The introduction of AWLAI also saw the transfer of the management of Australia's existing research and commercial capabilities in the Australian Astronomical Observatory (AAO) from the Government to the research sector. This resulted in the separation of the AAO into the Anglo-Australian Telescope (AAT), operated by a consortium of universities and Astronomy Australia Limited (AAL), and created the Astralis Instrumentation Consortium (Astralis).

[1] Australian Academy of Science (2015). *Australia in the era of global astronomy: Decadal plan for Australian astronomy 2016–2025 Mid-term review*. Canberra: Australian Academy of Science.

[2] Commonwealth of Australia (2017). Budget Measures, Budget Paper No. 2, 2017-18. https://archive.budget.gov.au/2017-18/bp2/bp2.pdf

This evaluation

The Department engaged ACIL Allen to conduct a mid-term evaluation of the AWLAI program, to assess its appropriateness, efficiency, effectiveness and impacts. We were also asked to examine the impact of changes in the management of the AAT. Other Australian Government programs and other optical telescopes in Australia are not included in the scope of this evaluation. Further detail is available in the Terms of Reference at appendix A.

The evaluation involved a desktop review, citation analysis (performed by Clarivate, citation analysis experts), a survey of members of the astronomy community with 124 responses, consultation with the Department and 25 stakeholders, analysis and reporting.

The total economic return of Australia's involvement in ESO was calculated by ESO using methodology developed by Technopolis Group, a UK-based consulting firm,[3] applying a cost-benefit methodology developed by the University of Milan.[4] The economic return is a sum of the *value of production of Australia's scientific output*, the *awarded VLT observing time*, and *industrial return* (i.e. industry contracts awarded to Australia). This sum is compared with Australia's cumulative financial contributions to ESO. This is further detailed in chapter 1. There are limitations to this methodology, as this does not consider (among other factors discussed in chapter 1) the:

- Lag time between research taking place and publications being released, and benefits being realised (which may occur over several decades).
- Potential benefits associated with broader socio-economic impacts, knowledge advances and innovations arising from research (which can lead to unexpected discoveries for the broader innovation ecosystem, such as WIFI, which resulted from astronomy research). Nor does it assess the value of advancements made by the research contained in, and resulting from publications. While these impacts are well recognised, they are challenging to quantify, and they are therefore not included in our analysis.
- Broader context of the ESO-SP, which provides a mechanism for the Australian astronomy community to collaborate with researchers from ESO member countries. Establishing those partnerships now should enable a more rapid flow of benefits in the event of a future full accession to ESO.

Findings of the evaluation

The evaluation found that the AAT is a well-built, high-quality facility that continues to deliver valuable scientific output. However, it is oversubscribed and due to its age, is no longer considered world-class. The operational life of the AAT could be extended beyond 30 June 2025. However, the scientific outcomes of the infrastructure are likely to gradually dimmish over the next 5-10 years and this will need to be considered against any potential future investment.

Overall, the ESO-SP has achieved its intended outcomes of ensuring access to 8-metre VLT telescopes and maintaining a critical mass of world-leading astronomy and instrumentation expertise in Australia. The ESO-SP has increased Australia's access to ESO facilities, its international competitiveness, the levels of collaboration, the quality and quantity of scientific output, and created workforce and training opportunities. AWLAI has also enabled synergies between ESO, AAT and SKA.

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[3] Technopolis Group (2021). *Socio-economic impact evaluation study of the UK subscription to ESO*. Accessed November 2023: https://www.technopolis-group.com/report/socio-economic-impact-evaluation-study-of-the-uk-subscription-to-eso/.

[4] Florio et al. (2015). *Cost-Benefit Analysis of the LHC to 2025 and beyond*. Accessed November 2023: https://arxiv.org/pdf/1603.00886.pdf.

Australia's return on investment in the ESO-SP to the end of 2023 has been neutral, with $1 of contributions to the ESO-SP generating approximately $0.97 in value for Australia from VLT observation time, scientific output, and industry returns in the form of ESO orders. However, as noted above regarding the limitations of the cost-benefit analysis, the broader, long-term value of the ESO-SP is likely to be much higher.

The ESO-SP has enabled access to, and award of, direct commercial tenders (valued at $9.3 million), industry collaborations, and the commercialisation of astronomy technical expertise. However, the tender opportunities would have been greater if Australia had been a full member of the ESO.

AWLAI has also supported a range of other Australian Government strategic priorities by benefitting other sectors. This includes the movement of skilled personnel and technology from astronomy to other high-value industries (e.g. the financial, high tech optical, software engineering and medical sectors).

Stakeholders noted that acceding to membership of the ESO would provide: long term stability for the astronomy community; ensure increased access to world-class facilities for Australian scientists; enhance the existing contracting opportunities for Australian businesses; and help maintain Australia's research excellence.

The key findings have been presented below according to the evaluation themes. The table also includes a cross reference to the section of the report where further information is available.

Table ES 1 Findings of the evaluation

Number	Finding	Evaluation theme	Further detail
1	There was, and continues to be, a clear need for Australian optical astronomy researchers to have reliable access to large telescopes to enable them to continue to deliver world leading science. This need was outlined in the 2016 National Research Infrastructure Roadmap and the Decadal Plan for Australian Astronomy 2016-25. AWLAI aligned strongly with the Australian Government's strategic policy objectives. Alternative approaches would not have been effective in maintaining Australia's astronomical excellence. Australian Government intervention was necessary to enable the ESO-SP and thereby secure continued Australian astronomy research excellence.	Need for the program. Alignment with government's strategic policy objectives	See section 2.1 for detail
2	The design of AWLAI was effective in positioning Australian astronomers to realise the intended astronomy research outcomes.	Design of the program	See section 2.2 for detail.
3	The Department has put in place appropriate structures to ensure good visibility of and input into the astronomy sector in Australia and internationally. The ILO role was, in principle, a good practice approach to industry engagement. However, some stakeholders said the role could have delivered more impact with better design and resourcing. Other stakeholders noted that tender opportunities were limited due to Australia's status as a strategic partner. The transition of the AAO to the AAT Consortium and Astralis was largely positive. While there were initial operational challenges and ongoing funding challenges, these organisations have strengthened and matured over time. Financial management of ESO-SP has been straightforward and without issues.	Program administration and delivery	See section 3.1 for detail.
4	The research sector's access to the AAT was not affected during the transfer to the AAT Consortium. Australia's instrumentation capability was maintained, and the level of collaboration and capacity increased following the transfer from AAO to the Astralis Consortium.	Impact of changes in program arrangements	See section 3.2 for detail.

Number	Finding	Evaluation theme	Further detail
5	Australia's return on investment based on the investment in and benefits to date from the ESO-SP is neutral, with every $1 of Australia's contributions generating approximately $0.97 in value for Australia. This is comparable with the findings of other international studies. ACIL Allen notes that this likely underestimates the full benefit delivered through the ESO-SP, including broader socio-economic impacts, knowledge advances and innovations arising from astronomy research. If these further benefits were included, the total benefit to Australia would be higher.	The program's value for money	See section 3.3 for detail.
6	The ESO-SP has achieved its intended outcomes of ensuring access to the 8 metre VLT and maintaining a critical mass of world-leading astronomy and instrumentation expertise in Australia. It has: – Increased Australia's access to ESO facilities, its international competitiveness, collaboration with Australian and international researchers, and the quality and quantity of scientific output. – Enabled access to and award of commercial tenders valued at $9.3 million, enhanced industry collaboration, and the commercialisation of astronomy technical expertise. This is despite the restrictions on industry opportunities available through the ESO-SP. There would be fewer restrictions, and more industry opportunities, if Australia were a full member of ESO. – Created workforce and training opportunities, including for students and postdoctoral fellows. However, ESO does not appear to be changing the gender diversity of researchers. The research output, impact, and productivity of the Australian astronomy community would be reduced without access to ESO facilities.	Outcomes and impacts of the ESO-SP	See section 4.1 for detail.
7	The research sector's *access* to the AAT reduced somewhat following the transfer. This was reportedly due to restrictions on non-AAT Consortium universities and the need to sell time to international researchers to help fund the telescope's operational costs. However, despite these factors somewhat reducing *access*, most survey respondents reported that the *quality* of research produced using the AAT largely remained the same during the transfer of AAT to the AAT Consortium, with growth in the number of publications and Australian research contribution to the AAT. The impact of Australian research using the AAT remained the same and is above world average.	Outcomes and impacts of AAT	See section 4.2 for detail.
8	Engagement in astronomy has delivered benefits to other sectors. This has occurred through the movement of skilled personnel from astronomy research and industry to other high-value industries, as well as spillovers of technology from astronomy to other fields. This supports a range of Australian Government broader strategic priorities.	Broader benefits from astronomy research	See section 4.3 for detail.
9	AWLAI has resulted in some negative unintended consequences, including funding constraints and challenges transitioning from AAO. While there have been challenges in establishing both the AAT Consortium and Astralis, stakeholders largely reported that these organisations have both strengthened and matured over time. Despite the issues noted above, AWLAI is delivering value to the astronomy community. Stakeholders stated that more certainty on future participation in ESO would be desirable.	Unintended consequences of the AWLAI program	See section 4.4 for detail.
10	Prior to accession, Australia would need to consider the costs and potential benefits of future membership. Acceding to the ESO Convention would provide long term stability for the astronomy community, ensure increased access to world-class facilities, help maintain Australia's research excellence, and enhance the existing contracting opportunities. If Australia decides to pursue accession, the benefits would likely increase due to increased access to facilities and tendering opportunities. Bringing the accession date forward would bring forward these impacts.	Impacts of acceding to ESO	See section 5.1 for detail.

Number	Finding	Evaluation theme	Further detail
	The ESO-SP is time limited. If Australia does not accede it will lose direct access to ESO facilities. While Australian astronomers may continue to access ESO facilities by partnering in research projects led by other countries, they could only lead projects that were awarded under ESO's Open Skies policy (which provide limited access). Australian companies would also lose any potential to tender for industry contracts. This would reduce Australia's current astronomy outcomes and forgo the potential outcomes that would be available under full membership. Whole-of-Government priorities continue to justify involvement in ESO, noting that the Australian Government is in the process of refreshing the National Science and Research Priorities. Any future decision on whether to fund full membership of the ESO will be made based on the government's objectives and priorities at the time.		
11	The AAT is a well-built, high-quality facility that is oversubscribed and delivers valuable scientific output. However, it is ageing, and no longer considered world-class. An extension to the current arrangements for AAT beyond 30 June 2025 would likely result in gradually diminishing scientific outcomes, and as such, there needs to be some longer-term clarity in the intentions for the AAT.	Impact of extending the AAT	See section 5.1 for detail.

Source: ACIL Allen

Table ES 2 provides the evaluation questions guiding the evaluation, cross-referenced to the relevant report section/s where the questions are discussed.

Table ES 2 Evaluation questions – cross-referenced to the discussion in this report

Design: 1. How appropriate was the design of the program?		
a) What was the need for the program and how well did it (and does it continue to) align with the Australian Government's strategic policy objectives?	i) Was the ESO-SP consistent with the Australian Government's strategic policy objectives?	Section 2.1.1
	ii) What Strategic priorities and goals (if any) was the Australia-ESO-SP required to address?	Section 2.1.1
	iii) How well did the design of AWLAI enable the desired project outcomes? What could be done differently or improved?	Section 2.2
	iv) Was Commonwealth intervention necessary to achieve the intended objectives of the program to secure continued Australian astronomy research excellence?	Section 2.1.3
	v) Did the ESO-SP address the objective to maintain Australia's optical Astronomy capabilities, and access to Astronomy infrastructure as identified by expert stakeholders in the Decadal Plan for Australian astronomy (2016-2025) (the Decadal plan)?	Section 2.1.1
	vi) What (if any) alternative approach could have been used to maintain Australia's astronomical excellence?	Section 2.1.2
Efficiency: 2. How well was the program administered and delivered?		
a) Was the program administered and delivered as planned? If not, how did it vary?	i) Has the ESO-SP performed as expected?	Section 4.1
	ii) What have been the effects of discontinuing Commonwealth operations of the Australian Astronomical Observatory?	Section 3.1.3
b) What worked well? What didn't work well or could have been improved or done differently?	i) Were ESO-related opportunities sufficiently translated into scientific, career and financial benefits for the Australian astronomy community?	Section 3.3 Section 4.1.1 Section 4.1.3
	ii) Was research sector access to the AAT affected during the process to transfer to the AAT Consortium?	Section 3.2.1
	iii) Was Australia's instrumentation capability affected during the process to transfer the Australian Astronomical Optics facilities to the Astralis Consortium?	Section 3.2.2
	iv) How effective has DISR been in establishing national capabilities in Astronomy, and ensuring Australian businesses are competitive in ESO tenders and global astronomy instrumentation and technology?	Section 3.1.1
	v) To what extent has the Industry Liaison Officer (ILO) assisted Australian Astronomy Institutions and relevant businesses to be competitive in ESO tenders and global astronomy instrumentation and technology?	Section 3.1.2
c) Has the cost of the program to date been justified by the benefits and opportunities it generates?	i) Do whole-of-Government priorities continue to justify the Commonwealth involvement in ESO?	Section 5.1.5

Outcomes: 3. Is the program working?		
a) What evidence is there that the program is achieving its intended objectives and outcomes? How do these outcomes compare to the results expected if the government had not intervened?	i) To what extent has the ESO-SP achieved its intended outcomes (i.e., access to 8m VLT telescopes and maintaining a critical mass of world-leading astronomy and instrumentation expertise in Australia)?	Section 4.1
	ii) Would the research output, impact, and productivity of the Australian Astronomy community be reduced without access to ESO Facilities? If so, do alternate approaches exist to ensure no loss of output, impact, and productivity?	Section 4.1.5
	iii) Has the ESO-SP improved Australia's production of astronomical instruments and technology and/or Australian Astronomers' international competitiveness and collaboration capacity?	Section 4.1.2 Section 4.1.1
	iv) To what extent has the ESO-SP generated industry opportunities through access to and award of commercial tenders, industry collaborations, access to global markets, and the commercialisation of astronomy technical expertise in other sectors?	Section 4.1.2
	v) Has access to the AAT increased, decreased, or remained the same for domestic astronomers?	Section 4.2.1
	vi) Has the quality and impact of AAT research increased, decreased, or remained the same?	Section 4.2.2
	vii) Has Australia's optical astronomy instrumentation capability and commercialisation of astronomy-derived practices, services and technology increased, decreased, or remained the same?	Section 4.1.2
b) What factors (internal and external) are helping and hindering the achievement of intended outcomes, or are likely to do so?	i) Would Australian benefits from the ESO-SP be likely to be increased, reduced, or unaffected by accession to the ESO Convention prior to the end of the ESO-SP?	Section 5.1.1
	ii) Are there any risks to failing to accede to the ESO Convention in a timely fashion (i.e., if there is a gap between the end of the ESO-SP and accession as full members)?	Section 5.1.3
c) What, if any, unintended consequences have there been, positive and negative, and for whom?	i) How has the current global financial situation and COVID pandemic affected the business case for ESO Membership?	Section 5.1.4
d) To what extent has the program contributed to, or enabled the outcomes it was designed to achieve?	i) Would an extension of the current arrangements for the AAT beyond 30 June 2025 result in a continued delivery of current AAT outcomes?	Section 5.2
	ii) Would an extension of the current ESO-SP beyond 2027, rather than accession to full membership, result in continued delivery of current astronomy outcomes?	Section 5.1.2
Lessons learned: 4. What lessons have been learned?		
a) What, if any, lessons can be drawn from AWLAI, and particularly the ESO-SP, to influence future astronomy policy and improve the efficiency and efficacy of similar programs going forward?		Section 6.2

Source: AWLAI Program Impact Evaluation – Statement of Requirements

Introduction 1

1.1 Context

The 2017-18 Budget included funding for measures designed to maintain Australia's capability in optical astronomy (the Maintaining Australia's Optical Astronomy Capability (MAOAC) budget measure). The *Access to World Leading Astronomy Infrastructure* (AWLAI) program was created to implement this budget measure and support Australia's optical astronomy activities.

AWLAI is administered by the Department of Industry, Science and Resources (the Department).

AWLAI enabled Australia to establish a Strategic Partnership with the European Southern Observatory (ESO), including access to the La Silla and Paranal Observatories (LPO) for 10 years to 1 January 2028. The budget provided funding of $129.2 million over 10 years.[5]

In February 2022, an amendment was made to the Australia-ESO-Strategic Partnership Arrangement (ESO-SP) to allow Australian astronomers to apply for observing time on ESO's APEX sub-millimetre antenna in Chile, and to enable Australian industry and astronomy institutions to tender for contracts under the ESO Technology Development Program.[6] In announcing the changes the then Minister for Science and Technology, Melissa Price, stated:

> *This new facet of our SP with ESO will enable our highly respected Australian institutions and businesses to contribute to global innovation and develop new technology.*

The introduction of AWLAI also saw the transfer of the management of Australia's existing research and commercial capabilities in the Australian Astronomical Observatory (AAO) from the Government to the research sector. This resulted in the separation of the AAO into the Anglo-Australian Telescope (AAT), operated by a consortium of universities and Astronomy Australia Limited (AAL), and created the Astralis Instrumentation Consortium (Astralis).

The stated purpose of AWLAI is to:

— ensure continued Australian astronomy research excellence through access to world-leading infrastructure
— address critical challenges for Australia's optical astronomy community
— maintain and strengthen Australian expertise in optical astronomy research and development
— create new international contracting opportunities, new capabilities and enable exposure to sophisticated technology development for Australian business.

[5] Commonwealth of Australia (2017). Budget Measures, Budget Paper No. 2, 2017-18. https://archive.budget.gov.au/2017-18/bp2/bp2.pdf

[6] European Southern Observatory (2022). *ESO and Australia strengthen their strategic partnership*. Accessed September 2023: https://www.eso.org/public/australia/announcements/ann22002/.

The Department defined the key criteria for measuring the success of AWLAI as an increase in the:

- level of international collaboration
- quality of scientific output
- commercialisation of technological innovation related to optical astronomy
- amount of industry collaboration with respect to ESO contracts.[7]

1.1.1 Australian Government's Investment in Astronomy

The study of astronomy is categorised based on the wavelengths of the electromagnetic spectrum being observed. Optical telescopes record visible light, radio telescopes record radio waves, infra-red telescopes record infra-red waves. More recently, there has been a growing presence around gravitational wave astronomy and neutrino astronomy.

Australia is world-renowned for research in optical and radio astronomy, and has strong representation in gravitational wave and particle physics astronomy. The synergies between the fields of astronomy and astronomy infrastructure are discussed throughout the report, as relevant.

Australia's investment in the construction of domestic Square Kilometre Array (SKA) precursors is building capacity in radio astronomy. This includes the Australian Square Kilometre Array Pathfinder (ASKAP), situated at the Inyarrimanha Ilgari Bundara, the CSIRO Murchison Radio-astronomy Observatory operated by CSIRO, and the Murchison Widefield Array (MWA), led by Curtin University.

Australia's domestic optical astronomy capability includes Australia's engagement in the ESO-SP, the 3.9 metre AAT at the Siding Spring Observatory in New South Wales, optical instrumentation design and build capabilities at Astralis (see section 1.2), and a myriad of privately owned a operated optical telescopes, as well as Australian researchers access to a number of international telescopes (including some ESO facilities) via 'Open Skies' policies (with some funding provided by the Australian Government through the Department of Education). Open Skies policies provide researchers of any nationality or affiliation the opportunity to apply for competitive access to non-guaranteed time, as long as they can demonstrate scientific excellence and the need for access to the specific facility (among other potential requirements that vary by facility).[8]

Australia leads research in a number of fields of astronomy. AWLAI focuses on optical astronomy, and in particular the Australian Governments' investment through AWLAI in the ESO-SP, AAT, and Astralis. AAT and Astralis also receive Australian Government funding through the Department of Education.

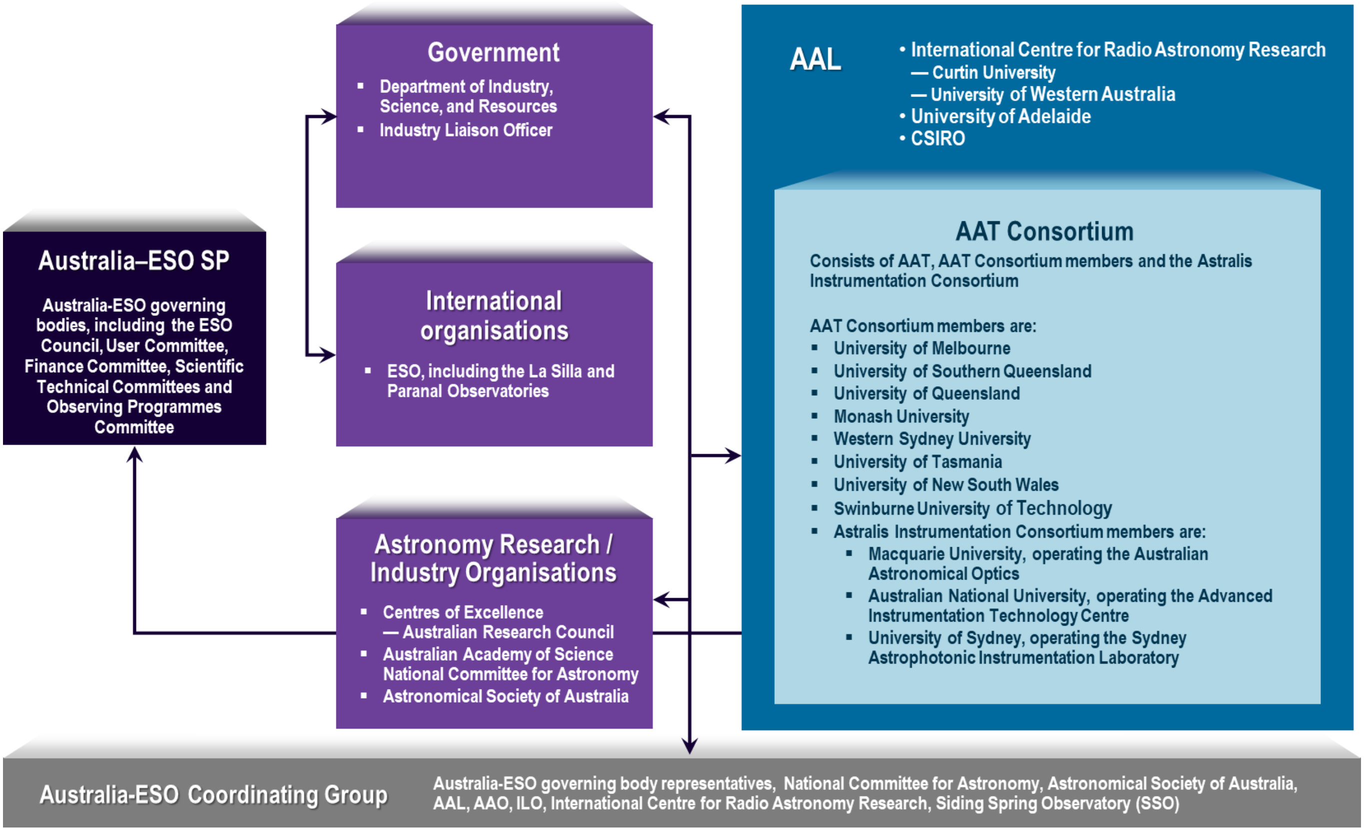
[7] The Department of Industry, Science and Resources (2023). *Statement of Requirements*. Canberra: Australian Government.

[8] ALMA Observatory (2021). *How ALMA Observations are carried out*. Accessed January 2024: https://www.almaobservatory.org/en/about-alma/how-alma-works/how-alma-observations-are-carried-out/.

1.2 Core components of AWLAI

AWLAI has several core components, as illustrated in Figure 1.1 and described below.

Figure 1.1 AWLAI program core elements



Source: ACIL Allen adapted from AAL

ESO-SP

The ESO-SP granted Australia access to the following LPO instruments:[9]

— Very Large Telescope (VLT, 8.2 metre)

— Very Large Telescope Interferometer (VLTI)

— VLT Survey Telescope (VST)

— Visible and Infrared Survey Telescope for Astronomy (VISTA)

— ESO 3.6 metre telescope

— New Technology Telescope (NTT).

Australia accesses these instruments under the same conditions and processes as ESO Member States. The ESO-SP also allows Australian businesses to bid on instrument procurement opportunities in relation to LPO facilities. However, this right does not extend to procurements for ESO's Extremely Large Telescope (ELT, 40 metre telescope), currently under construction, and set to be the largest optical telescope in the world. However, ESO is exploring the opportunity to potentially engage Australia in the future to assist with developing HARMONI for the ELT.

[9] European Southern Observatory (2017). *The Strategic Partnership between ESO and Australia*. The Messenger 169, September 2017.

Figure 1.2 Bird's eye view of the Very Large Telescope

Source: J.L. Dauvergne & G. Hüdepohl (atacamaphoto.com)/ESO. Accessed January 2024: https://www.eso.org/public/images/eso-paranal-51/.

Australia-ESO governing bodies and Coordinating Group

The ESO-SP entitles Australia to nominate a member to the ESO governing bodies outlined in Table 1.1.[10] The Australian representatives on these Committees represent the interests of the Australian Government by voting on matters regarding LPO telescopes and sites. Australia does not have the right to vote on all the matters that Member States do.

Table 1.1 Australia-ESO governing bodies roles and Australia's responsibilities

Committee name	Role	Australia's responsibility and representative type/s
ESO Council	The peak decision-making body of the ESO	Member - Observing government and astronomy representatives
ESO Committee of Council	Considers matters of Council level significance that do not require a decision	Member - Observing government and astronomy representatives
ESO User Committee	Advises ESO Director General on matters concerning the use of the ESO facilities (ALMA, Atacama Large Millimetre/submillimetre Array, and LPO) and is the main link between ESO and its user's community	Member - Astronomy representative with limited vote on matters regarding LPO
ESO Finance Committee	Considers astronomy and staffing matters with financial implications, and recommends decisions to the ESO Council	Member - Government representative with limited vote on matters regarding LPO
ESO Scientific Technical Committees for LPO (La Silla Paranal Committee) and ELT (ELT Subcommittee)	Considers scientific and technical matters related to the administration and development of ESO observatories	Member - Astronomy representative with limited vote on matters regarding LPO and ELT
ESO Observing Programmes Committee	Reviewing, evaluating on scientific merit, and ranking proposals submitted for LPO and advising the Director General on the distribution of observing time.	Member - Astronomy representative as a reviewer

Source: Department, 2023: Astronomy Branch Governance and Engagement List

[10] European Southern Observatory (n.d.) *ESO's Governing Bodies,* Accessed September 2023: https://www.eso.org/public/about-eso/committees.html

In 2017, the Department established the Australia-ESO Coordinating Group (Coordinating Group). This is comprised of Australia's representatives on the ESO Council and committees shown in Table 1.1, as well as representatives from the astronomy community, including the National Committee for Astronomy (NCA), Astronomical Society of Australia (ASA), AAL, International Centre for Radio Astronomy Research (ICRAR), Siding Spring Observatory (SSO, home of the AAT), Astralis – Australian Astronomical Optics, Australia's Industry Liaison Officer,[11] and the Department's staff member responsible for astronomy communications and outreach.

Each member of the Coordinating Group sources input from the astronomy community through their various networks to assist Australia's ESO Council representatives and ensure Australia presents a consistent, collaborative, broadly representative position in its engagement with ESO.

The Coordinating Group meets 4 times per year. Its role is to ensure a unified Australian approach to the strategic partnership with ESO and provide members with an opportunity to present the views and perspectives of the institutions and fields of study they represent.[12]

Astronomy Australia Limited (AAL)

AAL's members are Australian universities and research organisations with a significant astronomical research capability. AAL was established in 2007 as a not-for-profit company, limited by guarantee.[13] It represents the Australian astronomy community and plays a key role in supporting the progress of Australian astronomy.[14] AAL has 15 members,[15] some of which also participate in the Astralis Consortium and AAT Consortium (see Figure 1.1). AAL was established, with agreement from the wider astronomical community, as an impartial and independent body, to manage the Australian Government's $45 million National Collaborative Research Infrastructure Strategy (NCRIS) investment in astronomy infrastructure. From 2017-19 AAL received a further $18.3 million in operational funding from NCRIS and in 2022/23 secured $66 million in NCRIS funding for the following 5 years.[16]

AAL received just over $650,000 in grant funding from the Department between 2017/18 and 2021/22. This enabled AAL to manage stakeholder communication, monitor the demand for and use of ESO resources and opportunities, and track the impact and outcomes from ESO engagement. Reporting for the grant concluded in May 2023. The grant enabled AAL to:

— develop a database of Australian-led ESO proposals and publications (ESOStats)
— report to the Coordinating Group on ESO telescope demand and allocation of observing time
— curate an Australian ESO Forum, user guide, and details on applying for ESO observing time
— run in-person and online workshops on how to submit competitive ESO proposals
— promote ESO observing and employment opportunities, and ESO-sponsored events

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[11] Noting this position is currently vacant.

[12] Astronomy Australia Limited (n.d.), *Call for Nominations to the ESO Users Committee*, September 2023: https://astronomyaustralia.org.au/blog/news/call-for-nominations-to-the-eso-users-committee/.

[13] Australian Astronomy Limited (n.d.) *Who we are*. Accessed September 2023*:* *https://astronomyaustralia.org.au/who-we-are-astronomy-australia-ltd.html.*

[14] Astronomy Australia Limited (n.d.) *How we work*. Accessed September 2023: https://astronomyaustralia.org.au/how-we-work-astronomy-australia-ltd.html.

[15] Australian National University, CSIRO, Curtain University, Macquarie University, Monash University, Swinburne University of Technology, The University of Adelaide, The University of Melbourne, UNSW, the University of Queensland, University of Southern Queensland, The University of Sydney, The University of Tasmania, The University of Western Australia and Western Sydney University.

[16] Astronomy Australia Limited (n.d.). *AAL 2022/23 Annual Report*. Accessed January 2024: https://astronomyaustralia.org.au/aal-2022-23-annual-report/.

— conduct annual Australian ESO user surveys
— run the nominations process for Australian representatives on the ESO Council, User Committee, and Scientific Technical Committee.

The Industry Liaison Officer (ILO)

Australia appointed an ILO to help Australian firms access ESO procurement opportunities. The ILO's role is to be the primary contact between ESO and Australian industry. The ILO was employed at the equivalent of 0.2 FTE (in effect 1 day per week) from May 2018 to June 2023, funded through the Australian Government's Entrepreneurs Programme. In December 2023, the Department was in the process of recruiting a new ILO. The ILO's objectives are to work with Australian industry and astronomy institutions to:

— assist ESO in meeting procurement needs
— raise awareness of commercial opportunities from the ESO-SP
— develop capability and cultivate research-industry collaboration
— improve competitiveness in ESO tenders and global supply chains in astronomy and related fields.[17]

Australian Astronomical Observatory (AAO)

Established in 1974, the AAO was Australia's national optical astronomy facility until 2018. The AAO operated the AAT at Siding Spring Observatory in New South Wales and developed optical instruments at its headquarters in North Ryde.

The Australian Government repealed the *Australian Astronomical Observatory Act 2010* and dissolved the AAO in 2018. The operation of the AAT was assigned to a consortium of universities which formed the AAT Consortium, and AAO's optical instrumentation capabilities were redirected to form the Astralis Consortium, an overview of which is provided below.

The funding used to operate AAO ($12 million a year) was reallocated to contribute to the ESO-SP.

Anglo Australian Telescope (AAT)

The AAT's first images were obtained in 1974. The AAT is the largest optical telescope in Australia, with a diameter of 3.9 metres.[18] It has been critical to Australia's astronomy sector, and the quality of its optics and instrumentation have been integral to Australia's optical astronomy research.

At the time of construction, there were few large telescopes in the southern hemisphere. The construction, operation and maintenance were initially shared equally between the Australian and British Governments. The telescope was operated jointly until 2010, when ownership was transferred solely to Australia.

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[17] Department of Industry, Science and Resources (n.d.). *Optical Astronomy in Australia*. Accessed October 2023: https://www.industry.gov.au/science-technology-and-innovation/space-and-astronomy/optical-astronomy-australia.

[18] The Anglo-Australian Telescope, n.d., *About Us*, accessed September 2023, https://aat.anu.edu.au/about-us/AAT

Figure 1.3 The Anglo-Australian Telescope

Source: The Anglo-Australian Telescope. Accessed January 2024: https://aat.anu.edu.au/about-us/AAT.

When the AAO was dissolved, operation of the AAT was transferred to a consortium of 13 Australian universities, led by the Australian National University (ANU).[19] The consortium was established to fund, maintain and use the AAT. ANU was tasked with managing the operations of the telescope.[20] The second, and current, consortium agreement was established in 2022 and includes 11 university members. The AAT also sells observation time to international astronomers to secure additional funding for maintenance and upgrades.

The Department funded the AAT $4 million per year. When operations transitioned from the Commonwealth to the research sector in July 2018, the Department provided a grant of $2.3 million to support the replacement or renewal of specific aged or deteriorating telescope infrastructure, and the continuity of service of the AAT. From July 2018 to July 2022, the consortium of 13 universities provided $3.25 million for operations. From July 2022, the consortium of 11 universities is providing $2.85 million per annum. The Consortium and the Use Agreement expire on 30 June 2025.[21]

Astralis

In 2018, AAO's optical astronomy instrumentation capabilities were transferred to a new consortium, the Astralis Consortium. Astralis has a combined team of astronomy experts across 3 major Australian universities (see Figure 1.1):[22]

— Macquarie University, operating Australian Astronomical Optics

[19] DISR (n.d.) *Optical astronomy in Australia*. Accessed September 2023: https://www.industry.gov.au/science-technology-and-innovation/space-and-astronomy/optical-astronomy-australia

[20] Astronomy Australia Limited (n.d.) AAT, Accessed September 2023: https://astronomyaustralia.org.au/blog/portfolio/aat/

[21] Astronomy Australia Limited (2023). *Access to World Leading Astronomy Infrastructure - AAL Submission to the Evaluation Process.* Unpublished data.

[22] Astralis, (n.d.), *About Us*, Accessed September 2023: https://astralis.org.au/

- ANU, operating the Advanced Instrumentation and Technology Centre (AITC)
- University of Sydney (USYD), operating the Sydney Astrophotonic Instrumentation Laboratory.

Astralis receives funding from AAL. It develops, builds and tests custom designed, cutting-edge solutions to astronomical challenges, using advanced laboratories, testing and engineering facilities. Astralis has capabilities in building spectrographs and imagers, optical fibre and photonics technologies, adaptive optics, astronomy software, and technical systems management.

Astralis receives approximately $5 million per annum (for 10 years from July 2018) from NCRIS via AAL and generates revenue from commercial contracts.

1.3 This evaluation

The Department engaged ACIL Allen to conduct a mid-term evaluation of AWLAI.

The aim of the evaluation was to assess the design appropriateness, efficiency, and effectiveness of the AWLAI program. Furthermore, the evaluation examined AWLAI's short-, medium- and long-term impacts. It has assessed the extent to which the outcomes and goals are being, or are likely to be, delivered, in particular, the key goal of maintaining Australia's capacity and reputation for conducting world-leading astronomy research.

The evaluation also examines the impact of the changes in the management of the AAT and assesses to what extent the ESO-SP has provided for new opportunities for Australian businesses to develop and sell their technology to overseas buyers.

The Department's Statement of Requirements and evaluation framework have guided the evaluation. They are provided in appendix A.

1.3.1 Methodology

The evaluation involved a project inception meeting with the Department and preparation of a project work plan, a desktop review and citation analysis (performed by Clarivate), stakeholder engagement (see appendix B, including a survey and consultation), and analysis and reporting. Table 1.1 details the data sources, description and any limitations or assumptions.

Table 1.2 Data used in this evaluation

Source	Description of data
Evaluation survey	The survey was distributed by the Astronomical Society of Australia Inc. (ASA) to the ASA newsletter list of 784 members. Approximately 290 members are students or associate members, 72 are internationals, 46 are retired (and may be less likely to respond). The survey was open for 3 weeks from 31 August 2023 to 20 September 2023, with 2 reminder emails distributed during this time. A total of 124 responses were received, a 16% response rate.
Stakeholder interviews	A total of 25 interviewees were consulted for the evaluation across 14 interviews. This included videoconferences with interviewees from the following organisations: the Department, ESO employees, AAL, Astralis, AAT, ESO Coordinating Group, National Committee for Astronomy, and Australian businesses that have bid for ESO contracts. Notes were recorded during interviews to enable qualitative thematic analysis. Interviewees were provided with a discussion guide (see section B.2). Each consultation included at least 2 ACIL Allen team members. Consultations provided deeper and more current information than available from documentation and survey data, and enabled exploration of issues related to program processes and outcomes. Consultations also supported interpretation of the findings from the survey, desktop review and quantitative data analysis.
The Department	The Department provided information related to its management of AWLAI, engagement with ESO, and the allowable quantum of potential in kind contributions.
ESO	ACIL Allen reviewed material provided by ESO, including information on observing time on ESO's telescopes, ALMA observations, publications, industry engagement and returns, participation in the Observing Programs and review panels, media engagement, and calculated total economic return of the ESO-SP to Australia (or value for money).

Source	Description of data
	The total economic return was calculated by ESO using methodology developed by Technopolis Group. Technopolis Group, a UK-based consulting firm developed an approach for estimating the socio-economic impact of the United Kingdom's ESO membership,[23] applying the cost-benefit methodology developed by the University of Milan to assess the benefit of major research infrastructure.[24] The economic return is a sum of the *value of production of Australia's scientific output*, the *awarded VLT observing time*, and *industrial return* (i.e. industry contracts awarded to Australia). This sum is then compared to Australia's cumulative financial contributions to ESO. ESO *valued the production of Australia's scientific output* by attributing an economic value to knowledge production using ESO publication data and external information. This multiplies the average hourly wage of an Australian researcher by the average number of hours spent producing a paper. This 'value per paper' is then multiplied by the number of ESO papers with Australian-affiliated authors to attribute a value to Australia's production of knowledge through ESO. The *awarded VLT observing time* is calculated by multiplying the total awarded VLT observing time by the value of an hour of VLT observing time. The *industrial return* is a sum of the amount spent directly on Australian industry or institutes over the period of the ESO-SP (2018-22). There are limitations to this approach that should be considered. – There is typically a lag time between research taking place and publications being released. The lag time is highly variable and cannot be generalised across research teams and publications. A 2017 ESO study showed that the median lag time is approximately 5 semesters (i.e. 2.5 years), yet 50% of papers are published with 7 semesters and it takes 20 semesters for 95% of papers to be published. This analysis excludes Large Programmes, which account for a substantial fraction of Australia's VLT time during the ESO-SP. As such, the lag time is unknown for Australian researchers publishing papers using data obtained from leading ESO observing time. – The analysis does not consider publications made in 2023, as this data was incomplete at the time of finalising the report. – There are also lags between publications and benefits being realised. These may only emerge decades after the research takes place. – The analysis considers researcher wages, which represent a narrow measure of the value of a person's time and does not include the wider social value of a unit of labour. – Access to ESO facilities was restricted and receipt of proposals was limited in 2021. As such, the realised benefits may be limited, while Australia continued to pay ESO fees. This reduces the potential calculated value for money. – Calculations of the future potential benefit that may be obtained from observing time on the ELT are approximate. These calculations likely underestimate Australia's potential, as Australia could gain additional Guaranteed Time Observations from participation in second generation instrumentation. Further, this assumes that ESO is operating an Open Skies policy. Open Skies policies provide researchers of any nationality or affiliation the opportunity to apply for competitive access to non-guaranteed time, as long as they can demonstrate scientific excellence, the need for access to the specific facility, and that proposals are rated more highly than similar proposals submitted by ESO Members. If the ESO Council decides to temporarily restrict non-member access, then Australia's share of observing time would likely increase. These calculations do not take into account the value of any potential publications arising from research using the ELT under a full ESO Membership scenario. – The approach does not consider the potential benefits associated with broader socio-economic impacts, knowledge advances and innovations arising from research, nor assess the value of advancements made by the research contained in and resulting from the publications. While these impacts are well recognised, they are challenging to quantify, and they are therefore not included in the analysis. – The approach does not consider the broader context of the ESO-SP, which provides a mechanism for the Australian astronomy community to integrate into ESO, thus enabling greater benefits upon a future potential full accession to ESO. The ESO-SP has also provided the Australian community with access to ESO governance

[23] Technopolis Group (2021). *Socio-economic impact evaluation study of the UK subscription to ESO*. Accessed November 2023: https://www.technopolis-group.com/report/socio-economic-impact-evaluation-study-of-the-uk-subscription-to-eso/.

[24] Florio et al. (2015). *Cost-Benefit Analysis of the LHC to 2025 and beyond*. Accessed November 2023: https://arxiv.org/pdf/1603.00886.pdf.

Source	Description of data
	discussions (via participation in the ESO Council, Finance Committee, and Scientific Technical Committees, see Table 1.1), and prepared the Australian astronomy community for greater participation in the VLT and ELT instrumentation programs through exposure to the application and review process to date. This is a significant benefit that would be realised if Australia acceded to ESO. Consequently, ACIL Allen believes that the analysis is a conservative estimate of Australia's return on investment. The estimated value of benefits presented should be considered as an indicative estimate of the benefits delivered to Australia from its involvement in ESO to date, and of the future benefits that may be delivered over the remaining life of the ESO-SP, and potential full membership. It is likely that these benefits will increase with time.
AAL	ACIL Allen reviewed material provided by the AAL, including the annual ESO User Survey and insights on ESO outcomes. The ESO User Survey is an annual survey conducted by AAL in 2019 (16 responses), 2020 (24 responses), 2021 (15 responses) and 2022 (11 responses). AAL contacted principal investigators (PIs) to gather feedback on their user experience, including ESO use; collaborations, research training and funding; research outputs; benefits from the ESO-SP; and the least satisfactory, or most frustrating aspects of ESO user experience. See Appendix section C.2. The ESO outcomes dataset provided insights on time requested/allocated and the distribution of time allocated to different institutions and instruments. Reporting was provided for each ESO semester (a 6 month period, from April-September and October-March) from April 2018 to September 2023 (semesters 101-111), excluding semester 107, in which no Australian-led proposals were awarded time. This resulted from delays in previous semesters caused by the COVID-19 pandemic. See Appendix section C.3.
Citation analysis	Clarivate used scientific research publication data and citation analysis to identify research findings in Australian optical astrophysics. This included information such as research publications data and bibliometric indicators, which are part of the Clarivate core database, the Web of Science Core Collection™. Further details about the methodology are provided in the Clarivate report.[25]

Source: ACIL Allen

1.3.2 Structure of this report

This report presents the findings of the evaluation. Chapter 2 examines AWLAI design, chapter 3 discusses program administration and delivery, and chapter 4 discusses AWLAI outcomes and impacts. Chapter 5 considers future opportunities for key AWLAI program components and chapter 6 summarises the key conclusions.

Additional information is provided in appendices, including the terms of reference (appendix A), stakeholder engagement details (appendix B), and additional data and information (appendix C).

[25] Evaluation of the AWLAI program (2023), Clarivate Consulting, Australia

Program design 2

This chapter provides the evaluation findings on the AWLAI design, in particular, the need for AWLAI and its alignment with the Australian Government's strategic policy objectives.

2.1 The need for the program

Key Finding 1 The need for the program

There was, and continues to be, a clear need for Australian optical astronomy researchers to have reliable access to large telescopes to enable them to continue to deliver world leading science. This need was outlined in the 2016 National Research Infrastructure Roadmap and the Decadal Plan for Australian Astronomy 2016-25.

AWLAI aligned strongly with the Australian Government's strategic policy objectives. Alternative approaches would not have been effective in maintaining Australia's astronomical excellence.

Australian Government intervention was necessary to enable the ESO-SP and thereby secure continued Australian astronomy research excellence.

What was the need for the program and how well did it (and does it continue to) align with the Australian Government's strategic policy objectives?

Over time, it became increasingly clear that Australian researchers needed better access to larger telescopes to remain at the forefront of optical astronomy research. A proposal for Australia to join ESO was first developed in the 1990's but was unsuccessful.

Prior to the ESO-SP Australia had purchased observing time on 8-metre telescopes for several years, including Gemini, Subaru and Keck. However, this was expensive, with a total of 20-30 nights per year purchased for $4-5 million. This was funded by NCRIS and organised through AAL. Individual universities also negotiated their own access.

The purchase of observation time did not entitle Australian researchers to be involved in decisions in relation to the development of new infrastructure, to influence research priorities, or to bid for instrumentation contracts in relation to these telescopes. The research focus areas of these (mostly) northern hemisphere telescopes were also poorly aligned with Australian researchers' priorities due to the facilities' location, and there was limited capacity to undertake long-term studies (which require guaranteed on-going access to observation time).

In contrast, ESO's telescopes are much better suited to Australia's research priorities. The ESO-SP enabled Australia to trial ESO facilities to determine their value, with the option, but not commitment, to become a full member.

Interviewees identified a range of factors contributing to the need for AWLAI. These included Australian government and research sector priorities, the end of Australia's access to the 8-metre telescope under the Gemini program, and the end of the United Kingdom's funding of AAT. The time was also right from ESO's perspective as they were seeking to identify additional revenue streams to fund their activities. ESO was also keen to tap into Australia's astronomy research excellence and industry expertise (particularly in areas such as the remote operation of facilities).

The exploration of a possible ESO-SP began with a series of discussions between ESO and Australian astronomers. A proposal for a strategic partnership with ESO (the ESO-SP) was developed in late 2016 and provided to the Department. Negotiations with ESO followed and ultimately led to the execution of the ESO-SP in July 2017, providing access to the facilities from 1 January 2018.

2.1.1 Alignment with Australian Government and astronomy sector strategic objectives

What Strategic priorities and goals (if any) was the Australia ESO-SP required to address?

Was the ESO-SP consistent with the Australian Government's strategic policy objectives?

Did the ESO-SP address the objective to maintain Australia's optical Astronomy capabilities, and access to Astronomy infrastructure as identified in the Decadal Plan?

AWLAI aligns with the Australian Government's strategic policy objectives outlined in the 2016 National Research Infrastructure Roadmap (the Roadmap),[26] STEM (science, technology, engineering and mathematics) priorities, and the AUKUS security partnership.

In 2015-16, the Australian Government updated the Roadmap to include access to 8-metre telescopes through a partnership with, or membership of, a relevant organisation. The Roadmap identified Advanced Physics and Astronomy as a national research infrastructure area, and noted that new and emerging research areas require:

> *…access to larger scale, complex and sensitive instrumentation that is global in nature and operated by international partnerships and consortia.*[27]

The Roadmap stated that:

> *A paramount need for Australian optical astronomy today is increased access to international eight-metre-class telescopes… International arrangements are necessary to access overseas facilities for optical and radio astronomy.*

Access to 8 metre optical telescopes was seen as:

> *…necessary for Australia to continue to have the scientific expertise and technical capacity to conduct world-leading science… and maintain the nation's leadership in instrumentation.*[28]

AWLAI also aligns with the Decadal Plan for Australian Astronomy 2016-25 (Decadal Plan), developed by the Australian Academy of Science. The Decadal Plan identified the astronomy sector's science infrastructure priorities, including partnership equating to 30% access of an 8-metre telescope and 10% of a 30-metre telescope, and capabilities within AAO and the Australia Telescope National Facility (ATNF) to maximise Australia's engagement in global instrumentation projects. Radio astronomy and high performance computing and software capability were also identified as priorities.

A mapping of the 5 key purposes of AWLAI (see section 1.1) with the Decadal Plan and Roadmap shows strong alignment (see Table C.1). The ESO-SP partly addressed the Decadal Plan's goal of accessing 30% of an 8-metre telescope through providing access to 8% of ESO's LPO.[29] The goal of having access to 10% of a 30-metre ELT has been party met through a 6% access to GMT. Australia could secure access to the ELT through full ESO membership.

[26] Australian Government (2016). *2016 National Research Infrastructure Roadmap*. Canberra: Australian Government.

[27] Ibid.

[28] Ibid.

[29] Australian Academy of Science (2015). *Australia in the era of global astronomy: Decadal plan for Australian astronomy 2016–2025 Mid-term review*. Canberra: Australian Academy of Science.

AWLAI also commenced when the Australian Government was increasingly focusing on:

— The *National Innovation and Science Agenda*,[30] which outlined the need to increase industry-research collaboration to find solutions to real world problems and create jobs and growth.

— STEM education and skills, with the release of the Department of Education's *National STEM School Education Strategy 2016–2026*,[31] and the Office of the Chief Scientists' *STEM in the National Interest Position Paper*.[32]

— AUKUS security partnership, with Pillar 2 focusing on the need to develop advanced capabilities, to share technology and increase interoperability between Australia, the United Kingdom, and the United States.[33]

AWLAI also aligns with and contributes to these broader Australian Government priorities. Discussion on continued alignment is provided in section 5.1.5.

What (if any) alternative approach could have been used to maintain Australia's astronomical excellence?

2.1.2 Alternative approaches to maintain Australia's astronomical excellence

All interviewees reported that the only alternative approach to accessing observing time on large telescopes would be to buy time on other telescopes, or to collaborate with researchers from ESO member countries on ESO proposals.[34] Similarly, the evaluation survey shows that 28 of 46 respondents reported there was no realistic alternative to ESO facilities, 17 respondents reported that they would change the focus of their research or move away from Australia, 16 would attempt to leverage overseas networks, and 10 would attempt to access alternate telescopes (see Figure B.6). Survey respondents were not asked to identify whether they would continue to buy time on other telescopes, however, most survey respondents that were unsuccessful in receiving observation time on ESO facilities reported that they would reapply for ESO observation time (7 responses from 12 respondents). Other options included modifying their research project (5 responses), accessing ESO through collaborations (4 responses) or public data (including AAT data, 4 responses), or seeking time on other telescopes (3 responses).

Further, in the event of an alternative approach, Australian industry would not have been able to lead industry contracts for designing and building new research equipment, such as MAVIS (Multi-conjugate Adaptive optics Visible Imager and Spectrograph).

However, as noted above, all interviewees reported that alternative approaches would not have been effective in maintaining Australia's astronomical excellence or addressed the need to cost-effectively secure substantial observation time, and influence infrastructure development and research priorities.

In particular, some interviewees suggested that Gemini was not well used and did not deliver successful outcomes for Australian researchers. Reasons for this included the location of the Hawaii telescope (in the northern hemisphere, noting that one Gemini telescope is located in Chile), lack of alignment of Gemini's priorities with Australian researchers' focus, and the lack of

[30] Australian Government (2015). *National Innovation and Science Agenda Report*. Canberra: Australian Government.

[31] Department of Education (2016). *National STEM School Education Strategy 2016–2026*. Accessed September 2023: https://www.education.gov.au/australian-curriculum/support-science-technology-engineering-and-mathematics-stem/national-stem-school-education-strategy-2016-2026.

[32] Office of the Chief Scientist (2013). *Science, Technology, Engineering and Mathematics in the National Interest: A Strategic Approach July 2013, A position paper*. Canberra: Australian Government.

[33] L. Brooke-Holland (2023). *AUKUS pillar 2: Advanced capabilities*. Accessed September 2023: https://commonslibrary.parliament.uk/research-briefings/cbp-9842/.

[34] It would not be possible for an Australian researcher to lead such a proposal.

any voice in planning or choice of instrumentation. There was also difficulty to access sufficient nights of observing time to undertake larger projects.

Keck did not offer partnership options at the time and had limited observation time available for purchase. Subaru also had limited observation time available for purchase and no plans at that stage for future instrumentation development.

Was Commonwealth intervention necessary to achieve the intended objectives of the program to secure continued Australian astronomy research excellence?

2.1.3 The need for Government in the ESO-SP

The substantial funding required for the ESO-SP means that no single university or consortia was able to secure the necessary funding to engage with ESO. Further, there was strong agreement among the Australian astronomy community that it would not be economically viable, or suitable, for Australia to construct its own 8-metre telescope. As stated in the Decadal Plan:

> *We are now entering an era where the facilities underpinning Australian astronomy will be too large for sole Australian leadership of their infrastructure… Continued investment for Australian capability in areas including gravitational waves, high energy, and fundamental astrophysics will leverage investment in large international projects.*[35]

All interviewees agreed that Australian Government financial and policy support was needed to enable the ESO-SP and thereby secure continued Australian astronomy research excellence. Without Australian Government support, all interviewees reported that Australia would likely lose its competitiveness in research and its astronomy industry capability. This could lead to fragmentation of the astronomy sector and reduce the attraction and retention of skilled astronomy researchers.

2.2 Design of the program

Key Finding 2 The design of the program

> The design of AWLAI was effective in positioning Australian astronomers to realise the intended astronomy research outcomes.

How well did the design of AWLAI enable the desired project outcomes? What could be done differently or improved?

AWLAI was designed to meet the needs identified in section 2.1 and thereby address 4 broad aims, namely to:

— ensure continued Australian astronomy research excellence through access to world-leading infrastructure

— address critical challenges for Australia's optical astronomy community

— maintain and strengthen Australian expertise in optical astronomy research and development

— create new international contracting opportunities, new capabilities and enable exposure to sophisticated technology development for Australian business.[36]

Of the interviewees commenting on AWLAI's design, all reported that AWLAI was well designed and in line with these needs. They reported that without the design elements, and in particular the ESO-SP, Australia would not have been able to lead bids for instrument time and infrastructure contracts, or lead large research programs (referred to as Large Programs) on the VLT.

The core elements of the AWLAI design are discussed below.

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35 Australian Academy of Science (2015). Op. cit.

36 Department of Industry, Science and Resources (n.d.). *Optical astronomy in Australia*. Accessed September 2023: https://www.industry.gov.au/science-technology-and-innovation/space-and-astronomy/optical-astronomy-australia.

The design of the ESO-SP was successful in enabling Australia to access cutting-edge facilities and for Australian astronomers to lead joint research projects. This design element aimed to support stronger collaboration with European researchers, exchange of knowledge, and access to expertise and resources.[37] The ESO-SP also enabled Australian industry access to industry contracts (especially since the amendment in 2022, see section 1.1), with the aim of fostering greater industry commercialisation.

The establishment of the AAT Consortium and Astralis Consortium provided the necessary mechanisms to enable Australia to benefit from the ESO-SP and contribute to the development of the instrumentation used by the ESO-SP, and was in line with good practice internationally (discussed further in section 3.1.3).[38] While some interviewees acknowledged that there were initial challenges with the establishment of Astralis (see section 3.1.3), interviewees strongly supported the transfer of responsibility for AAO from the Government to the university sector. This also aligned with the Decadal Plan, which envisioned having "*a central body to promote and facilitate industry engagement with the next generation of global facilities*".[39]

While the ILO role was not a specific part of the original program's design, it was established to help facilitate contracting opportunities for Australian businesses (one of the broad aims outlined above). However, some interviewees noted that the role's part time nature and its location in Australia likely made it more difficult for the ILO to engage with ESO and potential European industry partners (discussed further in section 3.1.2). Stakeholders also noted that tender opportunities were limited due to Australia's status as a strategic partner.

The ILO's role to help industry obtain contracts to supply technology to the radio astronomy sector meant there was less time available to support industry seeking to supply the optical astronomy sector. In addition, opportunities for industry to tender for contracts prior to the 2022 amendment of the ESO-SP (see section 1.1) was relatively limited, hampering the ILO's potential to deliver industry outcomes. The amendment allowed Australian industry to participate in the ESO Technology Development Program. If industry were allowed to tender for ELT and ALMA contracts (i.e. as full ESO members) this would further increase their opportunities.

Overall, the design of the AWLAI program effectively positioned Australian astronomers to realise the intended astronomy research outcomes. However, it did not position Australia to have the opportunity to best realise industry outcomes.

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[37] Astronomy Australia Limited (2017). *Australia ESO Strategic Partnership.* Accessed September 2023: https://astronomyaustralia.org.au/blog/news/strategic-partnership-discussions-between-australia-and-eso/

[38] Astronomy Australia Limited (2023). Op. cit.

[39] Australian Academy of Science (2015). Op. cit.

Administration and delivery efficiency 3

This chapter provides the findings of the evaluation regarding AWLAI administration and delivery, in particular, whether the program was administered and delivered as planned, what worked well or could be improved, and the costs and benefits of the program.

3.1 Program administration and delivery

Key Finding 3 Program administration and delivery

The Department has put in place appropriate structures to ensure good visibility of and input into the astronomy sector in Australia and internationally.

The ILO role was, in principle, a good practice approach to industry engagement. However, some stakeholders said the role could have delivered more impact with better design and resourcing. Other stakeholders noted that tender opportunities were limited due to Australia's status as a strategic partner.

The transition of the AAO to the AAT Consortium and Astralis was largely positive. While there were initial operational challenges and ongoing funding challenges, these organisations have strengthened and matured over time.

Financial management of ESO-SP has been straightforward and without issues.

How effective has DISR been in establishing national capabilities in Astronomy, and ensuring Australian businesses are competitive in ESO tenders and global astronomy instrumentation and technology?

The Department has established a series of structures to coordinate Australia's national capabilities in astronomy and support Australian businesses through AWLAI. Financial management by the Department is also discussed below. It should be noted that few interviewees had visibility of, or commented on, the role of the Department in administering AWLAI. Questions of the Department's administration of AWLAI were not asked in the evaluation survey.

3.1.1 Australian engagement with domestic and international organisations

The Department has several processes in place to engage with the domestic and international astronomy community to deliver AWLAI.

The Department is an observer on the Astralis Instrumentation Consortium Board and a member of the National Committee of Astronomy and Australia-China Consortium for Astrophysical Research (ACAMAR) Australian Advisory Committee (ex-officio). The Department also regularly receives reports and briefings from, and engages with, the Astralis Board, AAT Council, the AAT Council Finance Committee and the AAL Board. These engagements each occur on multiple occasions throughout the year and provide the Department with insights as to the astronomy community's progress, plans and financial considerations.

Insights gained from domestic astronomy bodies inform Australia's representatives to ESO (as noted in Table 1.1). Department data shows that Australia has been consistently represented in all relevant ESO meetings by the Department or nominated astronomy representatives since the ESO-SP was put in place.[40]

As noted in Section 1.1, AAL provides critical support to the astronomy community, and is the key conduit by which the astronomy community's views are represented to the Department. The Department previously funded AAL to manage communication with the astronomy community, monitor the demand for and use of ESO resources and opportunities (see appendix C), and track the impact and outcomes of ESO (see section 1.1.1 and appendix C). The Department regularly engages with AAL staff on a wide range of issues including considerations to be incorporated into the possible development of a business case for full ESO membership.

However, AAL reported that it had poor visibility of the value and usefulness of its ongoing reporting to the Department. Improved communication would provide AAL with greater transparency and certainty that its reports were adding value. This would also allow the Department to identify areas of interest for reporting, to ensure that it is receiving the information it needs to inform policy.

Interviewees commenting on the role of AAL were all positive in AAL supporting instrumentation like MAVIS and in supporting the astronomy community to apply for ESO and AAT observation time. AAL was perceived to take a proactive approach and help address emerging challenges. This is evidenced by the evaluation survey, where most respondents reported that AAL was "*important* or *very important"* in supporting researchers to access time on AAT (83%, see Figure B.26) and ESO (75%, see Figure B.27) facilities.

To what extent has the ILO assisted Australian Astronomy Institutions and relevant businesses to be competitive in ESO tenders and global astronomy instrumentation and technology?

3.1.2 The role and impact of the Industry Liaison Officer

The ILO aimed to help connect businesses to ESO tender opportunities, and therefore grow high-tech industry sectors in Australia, provide small companies with access to European technology leaders, and expand the recognition of Australia's well-regarded expertise in remote operations robotics.

The ILO provided an essential point of contact for ESO to engage with Australia on potential procurements. Interviewees commenting on the ILO reported that this role was particularly important for Australia, as industry can only submit proposals if invited by ESO, and Australian industry capabilities were not well known to ESO when the ESO-SP commenced. As such, the Australian ILO needed time to embed within the ESO ecosystem.

Some interviewees reported that the ILO had relevant experience in working with firms that supply remote mining control systems and engaged with stakeholders early in the role to understand how Australian industry could be promoted to ESO (there is scope for remote mountain top observatories to draw on and use these mine-based technologies and control systems).

Most interviewees reported that the ILO role, and potential industry impact, was inherently limited, given the ESO-SP contracting arrangements (see section 1.1.1 and 2.2), limited time allocated to optical astronomy (see section 1.1.1), and their location in Australia instead of Europe.

For example, Australia initially did not have access to the main ESO Member mailing list, which hindered the ILO's awareness of procurement opportunities. One interviewee reported that few opportunities flowed through to Australian industry, and most of these were relatively small.

[40] This includes meetings from the 145th Council meeting, 92nd Committee of Council meeting, 149th extraordinary Finance Committee meeting, 90th Scientific Technical Committee meeting, and 42nd Users Committee meeting. Noting that Australia was not invited to attend the 146th extraordinary Council meeting, and was only invited to attend the opening of the 148th.

In contrast, ESO Member ILOs are well known to ESO, and there is a strong support system in place to connect with industry. The Member ILOs are also based in Europe, which most interviewees considered important in supporting their engagement with ESO and the European industry who provide technology and services to ESO. While the Australian ILO was part of the broader ILO network, and had access to ESO, several interviewees noted that this may have been improved by an on-the-ground presence in Europe.

Few interviewees had any interaction with the Australian ILO. This is supported by the evaluation survey, which shows that 87% of respondents had not interacted with the ILO in any way (see Figure B.31). Of those that did, survey respondents reported mixed experiences in terms of outcomes, with most not achieving any outcomes from this engagement (see Figure B.33). This is not unexpected, given that the interviewees were predominantly research focused.

One interviewee noted that of the few Australian businesses interested in responding to ESO tenders, some had declined the support of the ILO. This likely limited the influence the ILO had on responses to ESO tenders. One interviewee with direct experience with the ILO, considered that the ILO was highly successful in supporting their engagement, yet had been limited by the ESO-SP contracting arrangements.

For example, the ILO supported an Australian company to participate in an ELT tendering process and were encouraged to develop and present a proposal to ESO. However, they were later informed that they were not able to bid due to restrictions under the ESO-SP. While there may have been an opportunity to participate as a subcontractor, this would have required the organisation to share intellectual property, reducing their international competitiveness. This missed opportunity would have delivered substantial value to the organisation and partnering companies, which could have supported the project.

Some stakeholders said that the ILO could have delivered more industry benefit with additional time and resources, a sole focus on optical astronomy, and if Australia were to become a full member of ESO and be able to tender for all ESO contracts.

What have been the effects of discontinuing Commonwealth operations of the AAO?

3.1.3 Impact of discontinuing Commonwealth operation of the AAO

Interviewees largely reported that the university sector was better placed to operate the AAT, and that the transfer of AAT from Government to the university sector was a positive step. The change was reported to be in line with similar transfers internationally, as telescopes have aged, and operational budgets have reduced. The Department currently engages with the SSO, to administer the AAT Use agreement and AAT Maintenance and Continuity of Service grant with ANU. Current engagement focuses on leasing and financial matters such as insurance and maintenance.

Some interviewees reported that the transfer challenged the AAT Consortium to think differently and to work more collaboratively to continue AAT's operation.

However, there were also challenges associated with the separation. The budget for operating AAT reduced by 30% and the workforce by 40%. A 2021 review of the AAT found that the budget was 'insufficient for sustainable operations',[41] and that the funding and governance were overly complicated and caused inefficient decision making. Staff operating the facility also went from public service roles to temporary university contracts. This required a cultural shift and time to adjust.

Some interviewees reported that it was challenging for the university sector to quickly source funding to support AAT, which led to some negative impacts. For example, AAT has been funded using a series of short-term arrangements (3-4 years each), which limited the capacity for long-term planning and to attract and retain staff. The limited funding provided does not allow for significant

[41] AAT Review Panel (2021), Review of the Operations of the Anglo Australian Telescope.

changes in capability or proper maintenance of AAT, only incremental improvements. As such, when part of the facility breaks, and this disrupts paid observation time, funding needs to be returned to international astronomers who have booked time on the facility. As such, AAT interviewees reported the need for more coordination to align AAT maintenance and observing time with staff availability.

The transfer also separated astronomy researchers in the AAT Consortium from instrument technicians in Astralis. While interviewees were largely positive regarding Astralis' capability and capacity, the separation made it more difficult and expensive for astronomers to access instrument specialists and engineers, as they were no longer under one organisation and budget. However, the evaluation survey shows that 55% of respondents were unsure of whether Australia's instrumentation capability was affected after the management transfer to Astralis (see Figure B.29). This likely reflects that the survey respondents, primarily researchers, have limited engagement with Astralis (an industry-focused organisation). Of those that were familiar with Astralis' support, the most common response provided demonstrated they were content with the level of support provided (see Figure B.30). Many respondents also identified the need for further changes to increase the level of engagement of Astralis. This demonstrates its ongoing importance within the astronomy community.

A 2021 review by the Astralis Review Committee found that Astralis had achieved positive outcomes over its first 3 years, yet had fallen short of its initial objectives.[42] While Astralis was proactively seeking international optical instrumentation opportunities and delivered projects on time and budget, its capacity was limited, and the Review found that it would benefit from unified project management and delivery.[43]

Overall, while there have been challenges in establishing both the AAT Consortium and Astralis, interviewees largely reported that these organisations have both strengthened and matured over time.

3.1.4 Financial management of AWLAI

Australia has 2 scheduled contributions to ESO annually (January and July, within 30 days from receiving the invoice) as part of the ESO-SP agreement. Australia can make additional payments, to be held as credit, which can be used to reduce a later scheduled payment.

Financial management of the ESO-SP component of AWLAI has been straightforward.

Since the first payment in January 2018, Australia has had 3 delayed requests for payment, and 3 delayed payments. This has been at ESO's request due to ESO's positive cash position following COVID-19 delays to instrumentation and telescope construction projects, and the costs of holding deposits in European banks at a time when interest rates were negative.

Australia has also made 4 advanced contributions, invoiced by ESO at the Department's request. These were due to underspends elsewhere in the Department, and were approved by the Ministers.

[42] Astralis Review Committee (2022). Astralis Review.

[43] Ibid.

3.2 Impact of changes in program arrangements

Key Finding 4 Impact of changes in program arrangements

> The research sector's access to the AAT was not affected during the transfer to the AAT Consortium.
>
> Australia's instrumentation capability was maintained, and the level of collaboration and capacity increased following the transfer from AAO to the Astralis Consortium.

Was research sector access to the AAT affected during the process to transfer to the AAT Consortium?

3.2.1 Researcher access to AAT during the transfer to the AAT Consortium

Overall, the research sector's access to the AAT was not affected *during* the transfer of AAT to the AAT Consortium, due to a smooth transfer process. This is supported by the feedback provided during consultations with stakeholders and AAL's submission to the evaluation.[44] However, researchers' access to AAT was partially reduced *after* the transfer as AAT began selling observing time internationally (discussed further in section 4.2.1).

Was Australia's instrumentation capability affected during the process to transfer the Australian Astronomical Optics facilities to the Astralis Consortium?

3.2.2 Instrumentation capability during the transfer of AAO to the Astralis Consortium

Interviewees broadly considered that Australia's instrumentation capability was maintained during the transfer from AAO to the Astralis Consortium.

The creation of Astralis resulted in the development of a new space at USYD, providing expertise and resources, and enabled ANU's technology group to grow its capabilities and develop beyond astronomical instrumentation, with a focus on spectroscopic expertise. Macquarie University, the former location of the AAO, has continued to enhance its adaptive optics capabilities.

Astralis has focused predominantly on projects for the ESO VLT, including performing a leadership role in constructing MAVIS (discussed further in section 4.1.2). Astralis has in-demand skills in spectrographs, imagers, photonics and adaptive optics. These skills are being applied to both ESO and other projects, such as GMT, Gemini and Subaru telescopes. Astralis is now funded by NCRIS to seek further opportunities to collaborate with local industry.

Interviewees commenting on the consortium reported that its creation had enabled better collaboration on instrumentation and created a broader set of specialist skills and larger capacity (100 staff) to bid for contracts across the 3 nodes, and subcontract industry where needed. Different projects could also be transitioned seamlessly between nodes based on capabilities and infrastructure. This has enabled Astralis to be internationally competitive, and to have a much larger capacity for working on current and next generation telescopes than before AWLAI.

[44] Astronomy Australia Limited (2023). Op. cit.

3.3 The program's value for money

Has the cost of the program to date been justified by the benefits and opportunities it generates?

Were ESO-related opportunities sufficiently translated into financial benefits for the Australian astronomy community?

Key Finding 5 The program's value for money

Australia's return on investment based on the investment in and benefits to date from the ESO-SP is neutral, with every $1 of Australia's contributions generating approximately $0.97 in value for Australia. This is comparable with the findings of other international studies., and ACIL Allen notes that this likely underestimates the full benefit delivered through the ESO-SP, including broader socio-economic impacts, knowledge advances and innovations arising from astronomy research. If these further benefits were included, the total benefit to Australia would be higher.

3.3.1 Contributions to ESO and other AWLAI program costs

AWLAI was allocated a total of $132.1 million, or €86.2619 million as approved by the Australian Department of Finance, noting that the exchange rate was applied on 14 March 2017, and that this figure was subject to change based on fluctuations in exchange rate and inflation.

The funding includes:

- $129.2 million in ESO-SP contributions, over 10 years, from 2017-18 to 2027-28. This is split into:
  - operating fee of $92.8 million
  - contribution towards the capital investment of $36.4 million.
- Just over $650,000 in grant funding to AAL from the Department (to support their work liaising between ESO, Australian researchers and Australian industry). AAL also received substantial funding through NCRIS.
- $2.30 million in grant funding to the ANU to support the replacement or renewal of specific aged or deteriorating telescope infrastructure, and the continuity of service of the AAT.
- One Department FTE for 2017-18 and 2018-19 with 0.5 FTE in 2019-20 provided through internal Departmental resources, noting that the staff cost was offset at the time and that numerous staff worked on ESO, AAT, and AAL matters. Timesheets, where they are completed, do not contain sufficient detail to identify staff time spent on AWLAI matters.

A total of $78.6 million had been expended on the ESO-SP to November 2023.

3.3.2 Value for money assessment

While the benefits of the full AWLAI program have not been quantified, ESO analysed the value of ESO to Australia for the period of the ESO-SP, accounting for the additionality of the ESO-SP. The additionality of the ESO-SP is the value generated to Australia above and beyond the value already available to Australia through access to ESO through collaborations and public data.

ESO used a methodology developed by Technopolis Group, a UK-based consulting firm. This methodology estimated the socio-economic impact of the UK's ESO membership,[45] applying the cost-benefit methodology developed by the University of Milan to assess the benefit of major research infrastructure.[46] The full details of the ESO methodology are not publicly available, but details of ESO's approach were made available to ACIL Allen.

[45] Technopolis Group (2021). Op. cit.

[46] Florio et al. (2015). Op. cit.

ESO provided estimates of the benefit of ESO to Australia, based on observing time awarded to date on ESO facilities, the value of scientific output generated by ESO-related publications (by attributing an economic value to knowledge production using ESO publications data and external information), and industrial return.

The analysis methodology and findings are outlined below according to each calculated benefit area.

Value of Australian publications related to ESO

The value of publications resulting from Australian involvement in ESO has been calculated using the methodology, assumptions and data outlined in Table 3.1. The methodology involves calculating the total value of Australian ESO publications by multiplying the estimated value of a paper by the total number of Australian ESO publications. The estimated value of a paper was calculated by dividing the value of time dedicated to research (multiplying the proportion of time researchers dedicate to research by the average researcher salary) by the average number of papers per scientist (estimated based on the average number of ESO science archive users reported between 2012-22, divided by the number of Australian ESO publications).

This approach suggests that from 2013-22, the total value of Australian publications related to ESO is $122.5 million (in 2022 prices). This was an increase from an average of $10.2 million per year in the 5 years from 2013-17 (pre-ESO-SP), to an average of $14.3 million per year in the 5 years from 2018-22 (during the ESO-SP). This does not consider the additionality of the ESO-SP, which is discussed below.

Table 3.1 Value of Australian publications related to ESO (2013-22)

Factor	2013	2014	2015	2016	2017	Total pre-ESO-SP	2018	2019	2020	2021	2022	Total post-ESO-SP
(A) Number of Australian ESO publications Number of Australian ESO publications published in a year with at least 1 Australian author from Telbib[47]. Includes Australian authors that may and may not have led ESO research.	122	123	135	155	165	**700**	201	185	193	213	187	**979**
(B) Proportion of time dedicated to research Technopolis Group assumption based on methodology and data obtained from a survey of 50 scientists on the proportion of time dedicated to research (average response of 73%).[48]	0.7	0.7	0.7	0.7	0.7	**3.7**	0.7	0.7	0.7	0.7	0.7	**3.7**
(C) Average salary ($1,000) The average wage of an Australian researcher has been assumed at **$110,000** in 2022. This has considered average pays for Australian astronomy researchers using data from the Economy Research Institute, Times Higher Education, Glassdoor, and Payscale, and has been adjusted for inflation using the Reserve Bank of Australia inflation calculator.[49]	89.6	91.3	92.7	93.9	95.7	**463.2**	98.0	99.7	100.5	103.5	110.0	**511.7**
(D) Value of time dedicated to research (B x C) ($1,000) The average salary (B) multiplied by the average proportion of time dedicated to research (C).	65.4	66.6	67.7	68.5	69.9	**338.1**	71.5	72.8	73.4	75.6	80.3	**373.5**
(E) Average number of ESO papers per scientist Estimated based on the average number of ESO science archive users report between 2012-2022, divided by the number of Australian ESO publications. Average used for all years.	1.1	1.1	1.1	1.1	1.1	**5.5**	1.1	1.1	1.1	1.1	1.1	**5.5**
(F) Estimated value per paper (D / E) ($1,000) The value of time dedicated to research (D) divided by the average papers per scientist (E).	59.5	60.6	61.5	62.3	63.5	**307.4**	65.0	66.2	66.7	68.7	73.0	**339.6**
(G) Total value of Australian ESO publications (F x A) ($M) The value per paper (F) is multiplied by the number of ESO papers with Australian-affiliated authors to attribute a value to Australia's production of knowledge through ESO.	7.3	7.5	8.3	9.7	10.5	**43.2**	13.1	12.2	12.9	14.6	13.7	**66.5**
Inflation adjustment (using RBA inflation calculator for goods)[50]	23.0	20.0	18.2	16.7	14.5	**92.4**	12.4	10.6	9.6	6.6	0.0	**39.2**
(H) Total value of Australian ESO publications ($M) in 2022 prices (inflation adjusted)	**8.9**	**8.9**	**9.8**	**11.3**	**12.0**	**51.0**	**14.7**	**13.5**	**14.1**	**15.6**	**13.7**	**71.6**

Source: ACIL Allen, obtained from ESO data

[47] European Southern Observatory (n.d.). *ESO Telescope Bibliography*. Accessed January 2024: https://telbib.eso.org/.

[48] Technopolis Group (2021). Op. cit.

[49] See https://www.timeshighereducation.com/unijobs/listings/physics-and-astronomy/australia/, https://www.glassdoor.com.au/Salaries/astronomers-salary-SRCH_KO0,11.htm, https://www.payscale.com/research/AU/Job=Astrophysicist/Salary, https://www.erieri.com/salary/job/astronomer/australia.

[50] Reserve Bank of Australia (2024). *Inflation calculator*. Accessed January 2024: https://www.rba.gov.au/calculator/annualDecimal.html.

Calculating additionality

Australia has benefited from involvement with ESO through collaborations and access to public data. As such, the value for money assessment calculates an approximate baseline benefit provided to Australia for the period of 2013-17, and removes this from the calculated benefit delivered during the period of the ESO-SP (2018-22).

In this way, the value for money assessment includes only the approximate additional benefit delivered from Australia's involvement in the ESO-SP. The qualifications and data limitations outlined in Table 1.2 should be considered when reviewing the analysis.

The value of publications resulting from Australian involvement in the ESO-SP has been calculated using the methodology, assumptions and data outlined in Table 3.2. The methodology involves calculating the additional value of Australian ESO publications by:

1. Calculating the value of publications for the 5 years before the ESO-SP (2013-17), which is the assumed hypothetical baseline value of publications during the ESO-SP
2. Calculating the value of publications for the 5 years during the ESO-SP (2018-22)
3. Subtracting the hypothetical baseline value of publications during the ESO-SP from the actual calculated value of publications for the 5 years during the ESO-SP.

This shows that Australia received a total of $51 million in benefit from the value of publications in the 5 years from 2013-17 from its involvement in ESO before the ESO-SP. After the ESO-SP commenced, Australia received $71.6 million in benefit in the 5 years from 2018-22. As such, an estimated total of **$20.6 million in additional benefits** were delivered through the value of publications as a result of the ESO-SP.

Table 3.2 ESO-calculated additional value of publications resulting from Australian involvement in the ESO-SP, from 2018-22

Factor	Value (million AUD$)^	Value (million €)
(A) Total value of publications from 2013-22 See Table 3.1.	122.5	80.5
(B) Baseline value of publications before the ESO-SP (2013-17) and hypothetical baseline value of publications during the ESO-SP 5 years from 2013-17, as shown in Table 3.1.	51.0	33.5
(C) Value of publications during the ESO-SP (2018-22) As shown in Table 3.1.	71.6	47.0
(D) Additionality of the ESO-SP on the value of publications (C) minus (B)	**20.6**	**13.6**

^*Euro to AUD converted using ATO conversion average from FY end 2017-2023 ($1 = €0.657). Values rounded to 1 decimal place.*

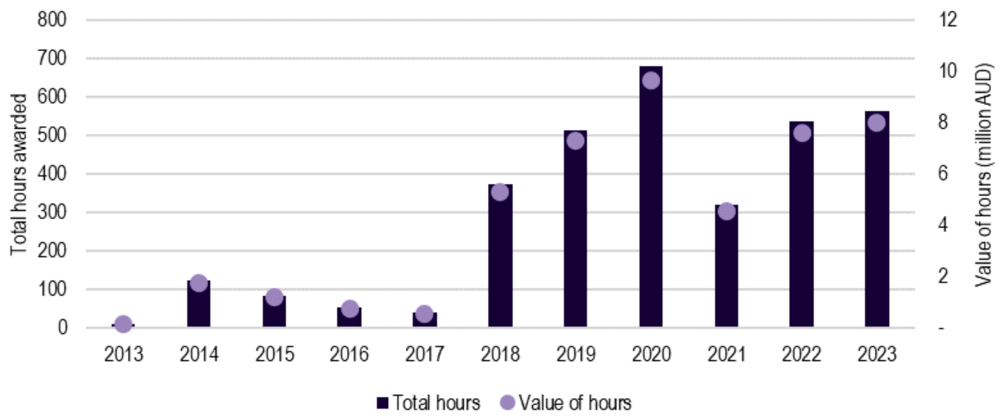
Source: ACIL Allen, obtained from ESO data

Value of awarded ESO observing time

ESO data shows that a total of 2,871 VLT hours were awarded to Australian researchers from 2013-23. ESO values this time at $16,322 (€10,723) per hour (see Figure 3.1).[51] The total value of hours awarded from 2018-23 was $42.4 million.

Note that the value of publications provided in Table 3.2 is calculated over 2018-22, while the value of awarded observing time in Figure 3.1 and Table 3.3 are calculated over 2018-23. This is because the 2023 VLT observing time had been awarded for the 2023 calendar year, while publications data was incomplete at the time of finalising the report.

Figure 3.1 Total number of hours awarded and value of hours (million AUD) per year



Source: ESO

Calculating additionality

The calculation of the value of awarded observing time resulting from Australian involvement in the ESO-SP is provided in Table 3.3.

The value of awarded observing time resulting from Australian involvement in the ESO-SP has been calculated using the methodology, assumptions and data outlined in Table 3.3. The methodology involves calculating the additional value of awarded observing time by:

1. Calculating the value of awarded observing time for the 5 years before the ESO-SP (2013-17), which is the assumed hypothetical baseline value of awarded observing time during the ESO-SP
2. Calculating the hypothetical baseline value of awarded observing time by calculating the average value of observing hours per year before the ESO SP, and multiplying this by the number of years of the ESO-SP (6 years from 2018-23)
3. Calculating the value of awarded observing time for the 6 years during the ESO-SP (2018-23)
4. Subtracting the hypothetical baseline value of awarded observing time during the ESO-SP from the actual calculated value of awarded observing time for the 6 years during the ESO-SP.

This shows that Australia received a total of $4.5 million in benefit from awarded observing time in the 5 years from 2013-17 from its involvement in ESO before the ESO-SP. After the ESO-SP commenced, Australia received $42.4 million in benefit in the 6 years from 2018-23. As such, an

[51] Euro to AUD converted using ATO conversion average from FY end 2017-2023 ($1 = €0.657). Values rounded to 1 decimal place.

estimated total of **$37 million in additional benefits was obtained** through the value of awarded observing time as a result of the ESO-SP.

Table 3.3 ESO-calculated additional value of awarded observing time resulting from Australian involvement in the ESO-SP, from 2018-23

Factor	Value (million AUD$)^	Value (million €)
(A) Total value of all observing hours 2013-2023 A total of 2,871 VLT hours were awarded to Australian researchers from 2013-23, at a value of €10,723.91 per hour.	46.9	30.8
(B) Baseline value of observing hours before the ESO-SP (2013-17)	4.5	2.9
(C) Average value of observing hours per year before the ESO-SP (B) divided 5 (the number of years before the ESO-SP from 2013-17)	0.4	0.3
(D) Hypothetical baseline value of observing hours during the ESO-SP (C) multiplied by 6 (the number of years of the ESO-SP from 2018-23)	5.4	3.5
(E) Value of observing hours during the ESO-SP (2018-23)	42.4	27.8
(F) Additionality of the ESO-SP on the value of observing hours (E) minus (D)	**37.0**	**24.3**

^Euro to AUD converted using ATO conversion average from FY end 2017-2023 ($1 = €0.657). Values rounded to 1 decimal place.
Source: ACIL Allen, obtained from ESO data

Value potentially delivered by Australia's involvement in the ELT

ESO provided estimates of the future potential benefit that may be obtained from observing time on the ELT, should Australia become a full ESO Member. These are approximate and conservative. The calculations likely underestimate Australia's potential, as Australia could gain additional Guaranteed Time Observations from participation in second generation instrumentation (such as for the ELT). Further, this assumes that ESO is operating an Open Skies policy. If the ESO Council decides to temporarily restrict non-member access, then Australia's share would likely increase.

Australia's benefits from the ELT have been calculated using the following assumptions:

- The known average proportion of time awarded to Australian lead researchers on VLT is **3.3%** averaged over the period of Australia's involvement in the ESO-SP (2018-23). This includes some of the most oversubscribed and competitive instruments.
  This is assumed to remain equal to the potential observing time awarded on ELT should Australia become a full member. This was considered by ESO to potentially represent a proxy indicator for expected ELT time.
- The average night length is **9.2 hours** (averaged over one year).
- This actual value of an observing night on the ELT is **$1.09 million** (€714,000) in 2023 dollars.
- The actual value of an observing hour is $118,125 (i.e. $1.09 million divided by 9.2 hours).
- The amount of science time at the ELT is 85% of the total available time.

As such, Australia's potential expected time awarded on ELT is:

365 days x 3.3% x 9.2 hours x 85% = 94.2 hours of ELT time per year

The annual value of ELT observing time is:

94.2 hours of ELT time per year x $118,125 per hour = $11.13 million per year

The 30 year value of ELT observing time is:

$11.13 million per year x 30 years = $333.82 million.

Overall value for money assessment

The overall value for money assessment compares the sum of the *value of production of Australia's scientific output* (see Table 3.2), the *awarded VLT observing time* (see Table 3.3), and *industrial return* (i.e. industry contracts awarded to Australia) to Australia's cumulative financial contributions to ESO.

The overall value for money assessment is provided in Table 3.4. This shows that from 2017-23, Australia made slightly more financial contributions ($69.1 million from 2017-23) than it has received financial benefit from its involvement in the ESO-SP ($66.9 million from 2018-23).

Collectively, this analysis shows a neutral return on investment, with every $1 of Australian contribution to the ESO-SP generating approximately $0.97 in value for Australia.

If Australia were to become a full member of ESO, access to ELT would generate substantial additional value in terms of Australia's likely observing time. Note that the value of potential publications arising from ELT have not been calculated under this potential full ESO membership situation. However, if Australia were to become a full member of ESO, the contributions to ESO would also increase (i.e. entrance and annual contributions, see section 5.1.1).

Table 3.4 ESO calculated return from Australian ESO-SP, from 2018-23

Factor	Value (million AUD$)^	Value (million €)
Value of production of Australia's scientific output (2018-22, see Table 3.2)	20.6	13.6
Value of awarded ESO observing time (2018-23, see Table 3.3)	37.0	24.3
Industry return (2018-22)	9.3	6.1
Total financial benefit	**66.9**	**44.0**
Australia's cumulative financial contributions to ESO (2017-23) *Note that this figure differs from the Department's total spending figures to date ($78.6 million) due to exchange rates and that ESO analysis was conducted earlier than the Department's assessment of total spend.*	(69.1)	(45.4)
Total return to Australia from involvement in the ESO-SP	**-2.2**	**-1.4**

^Euro to AUD converted using ATO conversion average from FY end 2017-2023 ($1 = €0.657). Values rounded to 1 decimal place.
Source: ACIL Allen, obtained from ESO data

The estimated rate of return is comparable to those found by other studies. For example, a 2011 report to Canada's National Research Council on benefits returned to Canada from use of Gemini and ALMA (noting that neither are based in Canada) stated that:[52]

> *Through a detailed economic modelling exercise, we estimate the benefit-to-cost ratio to be* ***almost one****. …the expenses incurred by the Canadian government for these two observatories ventures* [Gemini and ALMA] *are approximately equal to the quantifiable economic impacts for the country, which are in addition to the notable unquantifiable social benefits.*

An assessment of the UK's investment in ESO showed that an average ESO contribution of £22.7 million per year generated £45.5 million per year in benefits (£2.0 benefit for every £1

[52] Hickling, Arthurs and Low (2011). *Astronomy in Canada: Report to the Canadian National Research Council.*

invested).[53] Further, an additional UK investment of £88 million ($A170 million) in ELT beyond the UK's ESO membership contributions was expected to generate an equivalent or higher return on investment.[54]

Importantly, this is a conservative estimate of the value of ESO to Australia. As stated in Table 1.1, the analysis does not consider:

— The lag time between research taking place and publications being released (which are highly variable and cannot be generalised) or between publications and benefits being realised (which may only emerge decades after the research takes place).
— A broader measure of the value of a person's time and the wider social value of a unit of labour (only researcher wages).
— The value of production of Australia's scientific output (i.e. publications) delivered in 2023, or those that will be delivered in the future from research already undertaken.
— Restrictions in access to ESO facilities and receipt of proposals in 2021 (while Australia continued to pay ESO fees).
— The broader socio-economic impacts, knowledge advances and innovations arising from research, nor assess the value of advancements made by the research contained in and resulting from the publications. These impacts are challenging to quantify and monetise, and as such, have not been included.
— The potential for Australia to gain additional Guaranteed Time Observations from participation in ELT second generation instrumentation or the potential for ESO to restrict access to ELT to member countries (which would likely increase Australia's access and therefore benefit).
— The broader context of the ESO-SP, which provides a mechanism for the Australian astronomy community to integrate into ESO, thus enabling greater benefits upon a future potential full accession to ESO. The ESO-SP has also provided the Australian community with access to ESO governance discussions (via participation in the ESO Council, Finance Committee, and Scientific Technical Committees, see Table 1.1), and prepared the Australian astronomy community for greater participation in the VLT and ELT instrumentation programs through exposure to the application and review process to date. This is a significant benefit that would be realised if Australia acceded to ESO.

As such, the calculated return to Australia from involvement in the ESO-SP to date underestimates the total benefit. The values presented in Table 3.4 should be considered as an indicative estimate of the benefit delivered to Australia from its involvement in the ESO-SP to date, and indicative of the future benefit that may be delivered through access to ELT. The calculated return would likely increase over time as Australian researchers realised the benefit of access to ESO by delivering more publications. Further, inclusion of the broader socio-economic impacts arising from research would generate a significant increase in Australia's return from involvement in the ESO-SP.

[53] Ibid.

[54] Royal Astronomical Society (2016). *Astronomy means business: How UK research benefits industry, education and society*. Accessed August 2023: https://ras.ac.uk/ras-policy/impact-industry/astronomy-means-business-how-uk-research-benefits-industry-education-and.

Outcomes and impacts 4

This chapter provides the findings of the evaluation regarding AWLAI outcomes and impacts, in particular, achievement of program objectives and outcomes and factors helping and hindering outcome achievement.

To what extent has the ESO-SP achieved its intended outcomes?

Has the ESO-SP performed as expected?

4.1 Outcomes and impacts of the ESO-SP

Key Finding 6 Outcomes and impacts of the ESO-SP

The ESO-SP has achieved its intended outcomes of ensuring access to the 8 metre VLT and maintaining a critical mass of world-leading astronomy and instrumentation expertise in Australia. It has:

- Increased Australia's access to ESO facilities, its international competitiveness, collaboration with Australian and international researchers, and the quality and quantity of scientific output.
- Enabled access to and award of commercial tenders valued at $9.3 million, enhanced industry collaboration, and the commercialisation of astronomy technical expertise. This is despite the restrictions on industry opportunities available through the ESO-SP. There would be fewer restrictions, and more industry opportunities, if Australia were a full member of ESO.
- Created workforce and training opportunities, including for students and postdoctoral fellows. However, ESO does not appear to be changing the gender diversity of researchers.

The research output, impact, and productivity of the Australian astronomy community would be reduced without access to ESO facilities.

All interviewees considered that AWLAI has achieved its intended outcomes of ensuring access to 8-metre VLT telescopes and maintaining a critical mass of world-leading astronomy and instrumentation expertise in Australia. This is supported by the evaluation survey, which shows that a majority of respondents *strongly agree* that AWLAI is achieving its intended outcomes across research, competitiveness, commercialisation, and collaboration metrics (see Figure B.34). These metrics are further detailed below in sections related to each outcome area. A total of 53% reported that they *definitely would not* or *may not* have been able to achieve these impacts without AWLAI (see Figure B.36), noting that 42% were unsure, neutral or not applicable.

AWLAI impacts are described below according to key impact areas.

Has the ESO-SP improved Australian Astronomers' international competitiveness and collaboration capacity?

Were ESO-related opportunities sufficiently translated into scientific benefits for the Australian astronomy community?

4.1.1 Australia's world-leading astronomy expertise, international competitiveness and collaboration capacity

International competitiveness

ESO observing time is awarded based on scientific merit, and, as such, Australian researchers' success in securing observing time is due to their strong international competitiveness and astronomy expertise.

The ESO-SP has achieved its intended outcome of providing Australian researchers with access to the LPO facilities. Australian astronomers have gained good access to ESO facilities, including some of ESO's most important instruments. In the 5 years to 2023, Australian-led proposals were allocated more than 6% of total VLT observation time. This is comparable to the proportion of time allocated to longstanding ESO member states such as Germany, France, and Italy, when compared on a GDP-basis.[55]

ESO data shows that Australia's interest in and use of ESO's facilities has increased substantially from 2013-17 to 2018-22. This includes:[56]

— 5-fold increase in the number of proposals submitted per semester

— 4-fold increase in the number of Principal Investigators (PIs), and a 6-fold increase in the average number of successful PIs from an average of 1.8 per semester from 2013-17 (where Australian PIs could only lead research proposals made through ESO's Open Skies policy) to an average of 10 per semester from 2018-22 (which reflects that Australian researchers gained increased access to research proposals as PIs under the ESO-SP)

— an increase in observing hours requested from an average of 222 to 970 hours per semester

— an increase in the number of scheduled observing hours from an average of 31 to 220 per semester (7-fold increase).

This observing time has been allocated across a range of universities, with most observing time allocated to ANU, USYD and Swinburne University (see Figure C.13). Most observing time is allocated to VLT instruments (87%),[57] and mostly on ESO's MUSE and XSHOOTER (see Figure C.14). This is notable, as some interviewees reported that MUSE was a genuinely transformational instrument that is routinely the most oversubscribed ESO instrument.

Some interviewees reported that access has improved over time as researchers have become more familiar with the application requirements and process, AAL has provided ongoing proposal support, and the quality of applications has improved (as demonstrated by an increase in the average number of successful PIs and number of scheduled observing hours described above). Interviewees reported that the process of applying for ESO observing time was streamlined and worked well.

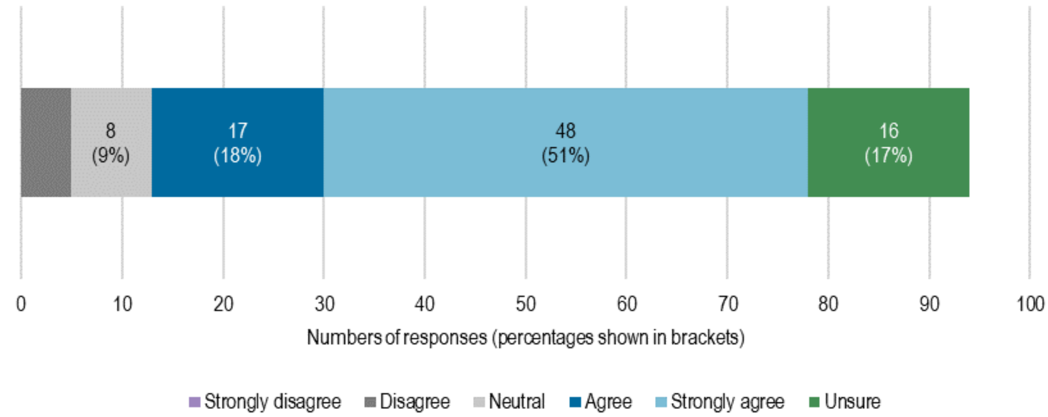
Some 69% of survey respondents either *agree* or *strongly agree* that AWLAI has increased Australian astronomers' international competitiveness and reputation (see Figure 4.1). Some interviewees also identified a strong international competitive advantage in Australia's combined expertise and capabilities in optical and radio astronomy. As many research projects require input from both types of facilities, this enables Australian researchers to cover a broader range of spectra and phenomena, and as such, this likely increases the complexity of the research that can be undertaken, and the potential impact of research findings. This is discussed further in section 4.1.4.

[55] Astronomy Australia Limited (2023). Op. cit.

[56] European Southern Observatory (2023). ESO-Australia Data 2023. Unpublished data.

[57] Ibid.

Figure 4.1 To what extent do you agree that AWLAI is achieving its intended outcomes of increasing Australian astronomers' international competitiveness and reputation?



n=94

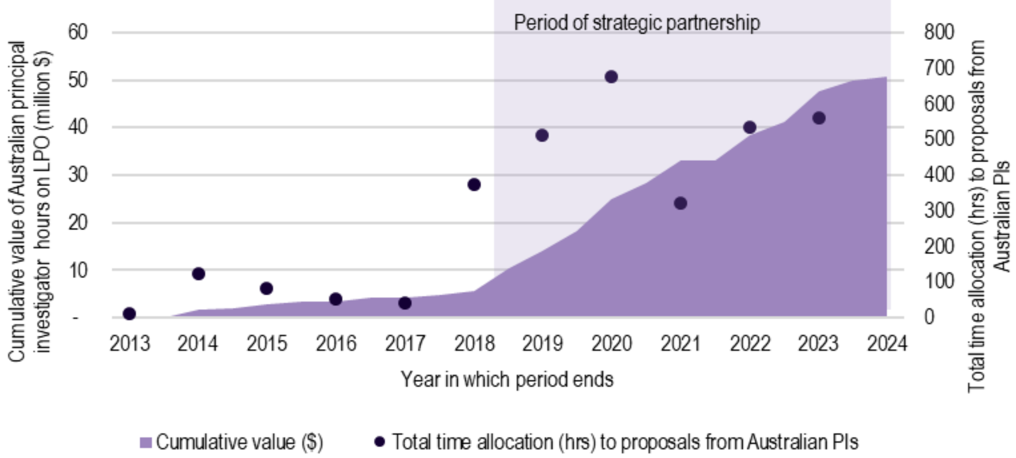
Source: ACIL Allen 2023 Survey of the astronomy sector

Value of observing time

The value of observing time awarded to Australian researchers on LPO instruments increased significantly from 2013-23. This reflects that Australian researchers have gained increased access to research proposals as PIs under the ESO-SP. Previously, Australian PIs could only lead research proposals made through ESO's Open Skies policy.

The total value of observing time awarded to Australian researchers has been valued by ESO at $46.9 million from 2013-23 (or $164,018.30 (€98,660) per night, see Figure 4.2), 90% ($42.4 million) of which was awarded since the ESO-SP began (2018-23). Australia has increasingly applied for fewer, yet larger projects, with more nights of observation time (see Figure C.9 and Figure C.10). As such, the overall number of nights awarded has increased.

Figure 4.2 Cumulative value of Australian principal investigator hours on LPO (million $)



Source: ACIL Allen, European Southern Observatory (2023).

Large Programs and Open Skies

Australian-led proposals have been awarded time to carry out 4 Large Programs (these are projects that require more than 100 hours of observing time over one or more semesters). This accounts for a large proportion of Australia's total allocated observing time on the VLT. This amount of observing time has not been achieved by any other member state within their first 5 years as members of ESO.[58] Most recently, 88% of Australia's scheduled observing hours were for a Large Program on the VLT. Again, this proportion of observation time awarded for Large Programs far exceeds the average for ESO Member States, which is only 25%.[59]

Large Programs allow researchers to undertake large monitoring projects, ask multiple questions, collect large sample sizes, and have confidence in the data events. The programs are highly competitive and tend to lead to significant scientific discoveries, research impact and the publication of multiple papers. Some interviewees considered the time awarded for Large Programs as a huge success that has provided greater stability and continuity to Australia's researchers and enabled substantial research projects to take place. As such, the time awarded for Large Programs, particularly so early on in Australia's partnership with ESO, reflects the excellence of Australia's astronomy researchers.

Australia has also gained access to ALMA through the ESO's 'Open Skies' policy. Open Skies provides access to non-guaranteed time that is available for researchers to apply for. Researchers can be of any nationality or affiliation as long as they can demonstrate scientific excellence, the need for access to the specific facility, and that proposals are rated more highly than similar proposals submitted by ESO Members. Two of the three proposals scheduled during ALMA's recent cycle were for projects with Australian Principal Investigators (PIs). This demonstrates Australia's interest in (and demand for) ALMA, as well as Australia's competitiveness in accessing ESO facilities (even without guaranteed time). This demonstrates that Australia has the potential to secure additional time through full membership, as membership would provide guaranteed time on ALMA, in addition to what could potentially be accessed through the Open Skies program. If Australia did not become a full ESO Member, it would need to continue to access ALMA through the Open Skies program (and thus receive more limited observing time).

Research publications

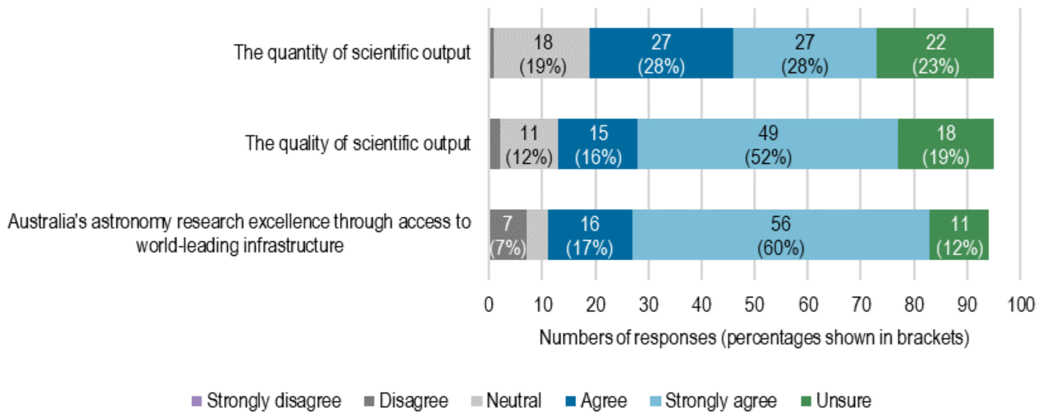
Most interviewees considered that the ESO-SP has performed as expected in terms of astronomy researchers' access and impact. This is supported by the evaluation survey (see Figure 4.3), which shows that a large proportion (72%) of respondents *agreed* or *strongly agreed* that AWLAI had supported Australia's astronomy research excellence by providing access to world-leading infrastructure. A clear majority of survey respondents also agreed or strongly agreed that AWLAI had increased both the quality (64%) and the quantity of scientific output (54%).

Further, the Australian ESO User Survey shows that researchers most commonly reported that either all, most, or at least half of their total allocated ESO observing time was ultimately used and was useful for their research (see Figure C.2). The proportion fell from 75% in 2019 to 53% in 2021 (likely due to the COVID-19 pandemic), before increasing to 82% in 2022.

[58] Astronomy Australia Limited (2023). Op. cit.

[59] European Southern Observatory (2023). Op. cit.

Figure 4.3 To what extent do you agree that AWLAI is achieving its intended outcomes of increasing:



n=95

Source: ACIL Allen 2023 Survey of the astronomy sector

Australia's international competitiveness and research capability can be observed through publishing data. Australian authors and researchers are defined as follows:

— **Australian authors** are Australian researchers that have contributed to producing a publication. An Australian researcher may:
  – be named as an author on a paper even if they are not included as a named researcher on an ESO proposal (i.e. through collaboration or use of public data)
  – lead the authorship of a publication but not be the lead researcher on the ESO proposal.

  As such, Australian authors published and could lead papers using ESO-related research before the start of the ESO-SP.

— An **Australian researcher** can lead an ESO proposal (only since the start of the ESO-SP, or via ESO's Open Skies policy before the ESO-SP), and can do this with or without being the lead author of a publication.

Figure 4.4 shows the total number of papers using VLT/I (VLT and/or VLTI) research with one or more Australian authors from 2000 to 2023, and the number of papers published using ESO research led by Australian researchers since the start of ESO-SP. The number of papers using VLT/I research with one or more Australian authors increased from an average of 68 per year from 2013-17 to 80 per year from 2018-23 (see Figure 4.4). The number of papers arising from research led by Australian researchers has increased over the life of the ESO-SP from 1 in 2018 to 16 in 2023. In total, 15% of papers authored by PIs on Australian-led ESO proposals have been in high-impact[60] journals such as Nature and Science (compared to an average of 2% across all ESO publications).[61]

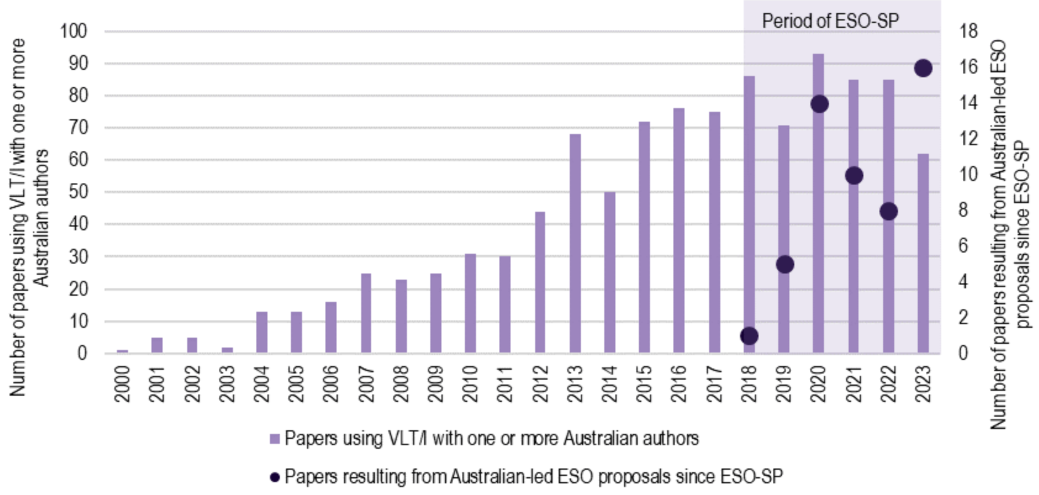
As the publication of scientific papers can often take years due to the time required for experimental design, data gathering, and writing, the number of papers can lag the use of ESO facilities by Australian astronomers.

[60] A journal's impact factor is a measure of the frequency with which an average article in a journal has been cited in a particular year. High-impact journals are considered to be highly influential in their fields.

[61] Astronomy Australia Limited (2023). Op. cit.

In addition, researchers also produce conference talks/posters, press releases, social media posts, public talks and receive awards/honours based of their research findings and published scientific papers (see Figure C.7).

Figure 4.4 Number of VLT/I papers with one or more Australian authors and number of papers from ESO research led by Australian researchers, by year



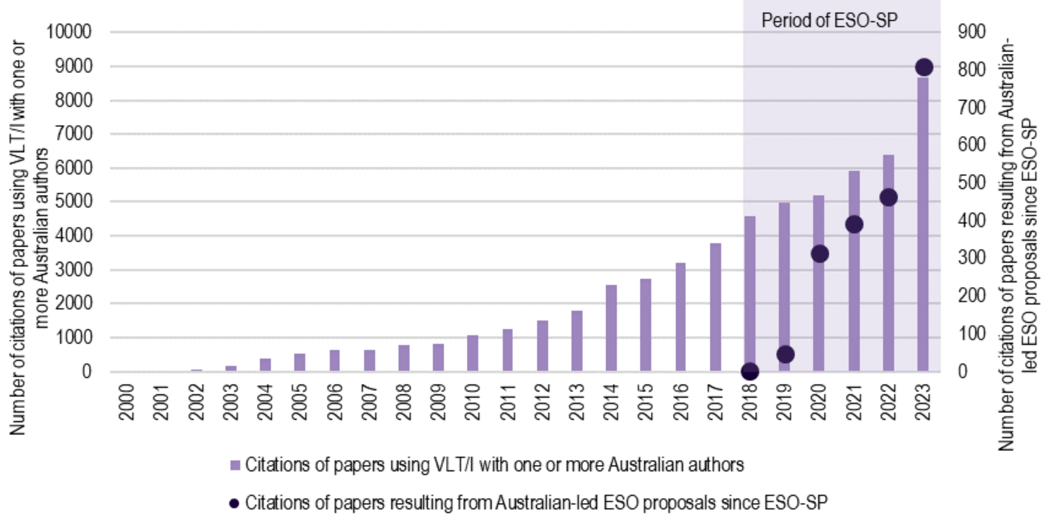
Note: As of 31 December 2023

Source: ACIL Allen, Astrophysics Data System Public Library

The number of citations from papers with one or more Australian authors increased from an average of 2,814 per year from 2013-17 to 5,955 per year from 2018-23 (see Figure 4.5).

The number of citations from papers arising from ESO research led by Australian researchers increased over the life of the ESO-SP from 2 in 2018 to 811 in 2023. This reflects that research continues to be relevant for, and deliver impact to, the astronomy community.

Figure 4.5 Number of citations of VLT/I papers with one or more Australian authors and number of citations of papers from ESO research led by Australian researchers, by year



Note: As of 31 December 2023

Source: ACIL Allen, Astrophysics Data System Public Library

Clarivate citation analysis provides a comparison of Australian performance with that of other countries. This shows that:

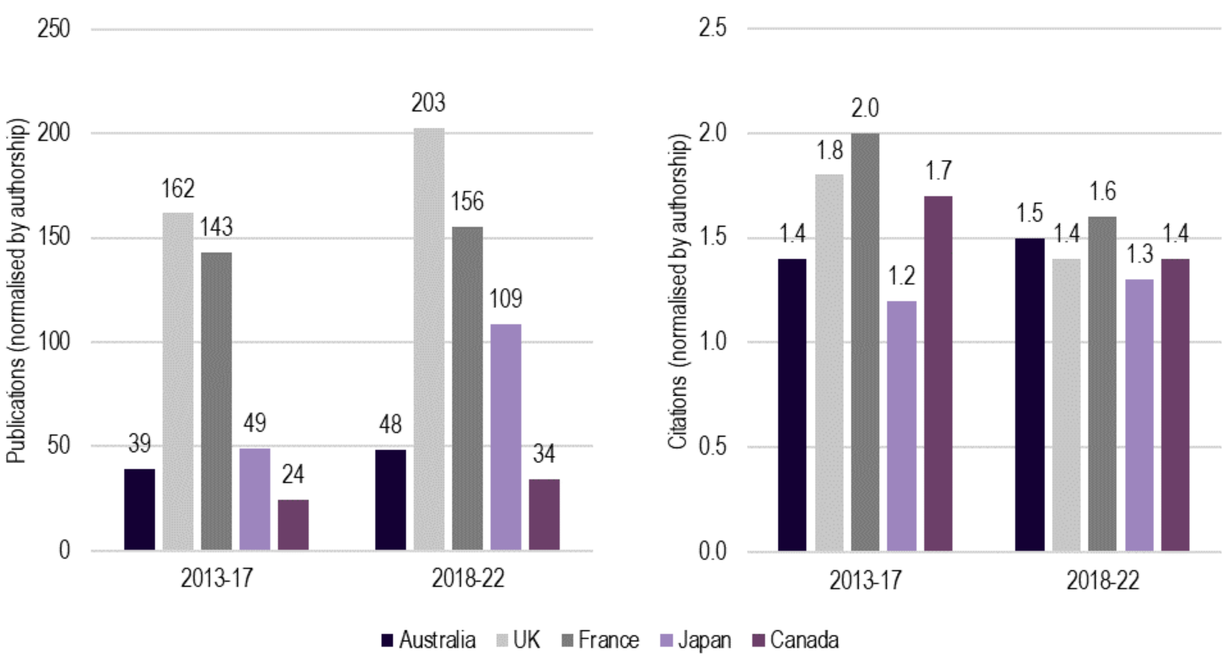
— While Australian research output (number of publications) in Astrophysics is lower than the comparator countries (UK, France, Japan, Canada), it has grown the fastest (6%) from 2013-17 to 2018-22. Australian research output in Optical Astrophysics is also lower than comparator countries, and increased by 1%, while no comparator countries increased their research output.

— Australian research impact in Astrophysics and Optical Astrophysics is comparable to the impact of the comparator countries and has remained relatively stable over time.

— The number of Australian research publications related to ESO is lower than for the comparator countries. However, the impact (measured by citations normalised by authors[62]) of that Australian research is comparatively higher (see Figure 4.6).

Figure 4.6 Number of scientific publications) and impact (normalised citations) associated with use of the ESO telescopes

Research using ESO telescopes	***Impact of research using ESO telescopes***



Source: Clarivate

Australian astronomers have also participated widely in ESO's Observing Programme Committee (OPC, see section 1.2) and review panels. This is because panel members are selected according to their excellence within the astronomy community and publication track-record. ESO notes:

> *"Serving on the OPC and its review panels helps define scientific excellence in astronomy and serves as a strong indicator of a national scientific community member's contribution."*

While this is an indicator of Australia's success, it does not necessarily cause improved success rates for researchers in applying for ESO observing time. Australia has been involved in all OPC meetings for eligible ESO semesters, chaired meetings for 3 ESO semesters, and been represented by at least one member at all OPC Review Panels.[63]

62 Australian researchers' contribution to ESO has been estimated by measuring the relative share of Australian researchers on publications, called fractional counting, or authorship-normalised publication count.

63 European Southern Observatory (2023). Op. cit.

Collaboration

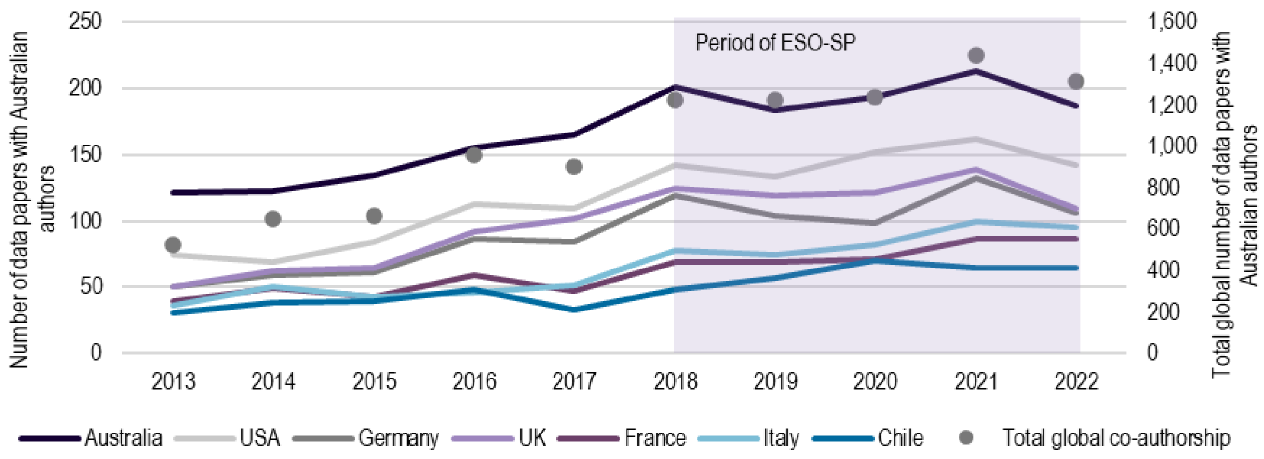
Some interviewees noted that Australian researchers are renowned for their skills in international engagement and undertaking collaborative research and industry projects. This has been supported by various Centres of Excellence (ASTRO 3D: Centre of Excellence for All Sky Astrophysics in 3 Dimensions, and OzGrav: Centre of Excellence for Gravitational Wave Discovery, noting that these are funded separately to the ESO-SP, yet are competitively awarded and could reflect Australia's broader astronomy excellence, which the ESO-SP contributes to), which deliver national and international conferences and support the astronomy community.

Some of the interviewees highlighted the value of international collaboration and mobility in astronomy. Australian astronomers, including students, visit ESO facilities and engage with the instruments in person and to learn from world-class international researchers. This knowledge is shared among researchers in Australia, with ESO data often used to inform several projects and train a range of researchers.

ESO has sponsored 3 international astronomy conferences in Sydney (2019), Perth (2020), and Canberra (2023). These have been important in fostering collaboration between Australian and European astronomers.[64] Further collaboration has occurred between Australian students and academics and ESO through scientific exchanges, discussed further in section 4.1.3.

Records of Australian co-authorship with researchers also highlight Australia's growing collaboration. Figure 4.7 shows Australia's co-authorship from the top 6 global countries from 2013-22, and the Australia's total global involvement. Australia's co-authorship across its top 6 collaborating countries and global co-authorship has increased between the period before (2013-17) and after (2018-22) the ESO-SP. For example, total global co-authorship increased from an average of 742 papers per year from 2013-17 to an average of 1,290 papers per year from 2018-22.

Figure 4.7 Number of data papers with Australian authors, by country (top 6 collaborators)



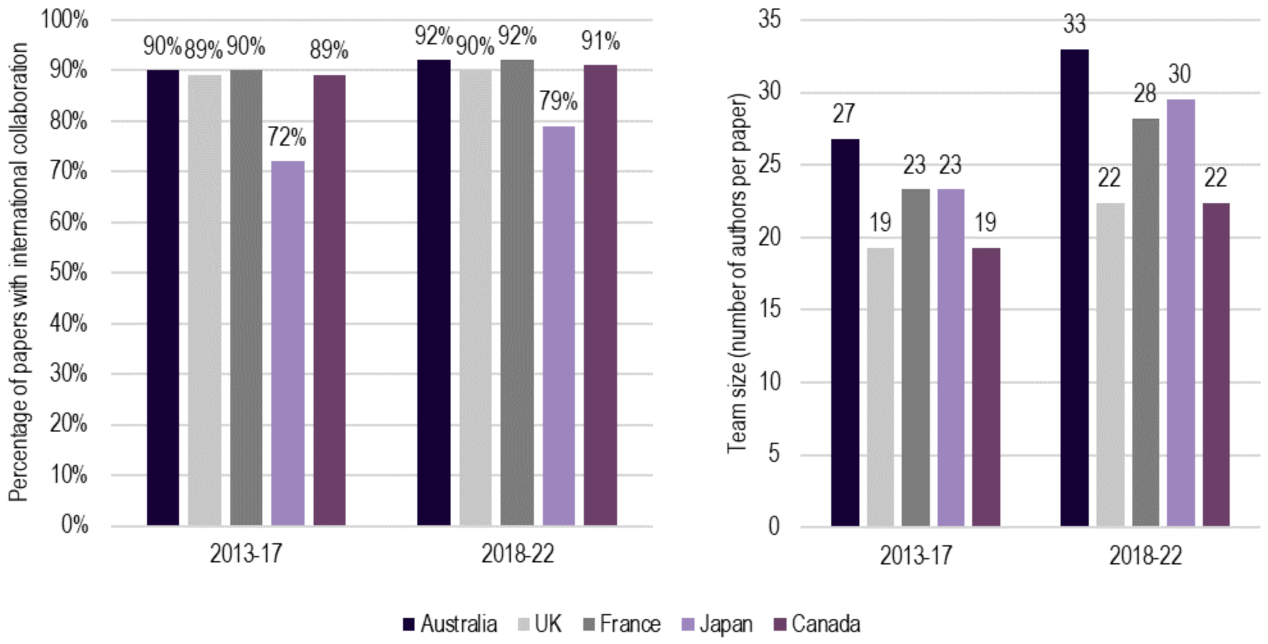
Note: The line for Australia is not the sum of the other lines (because a paper with an Australian author can have authors from one or more other countries).
Source: ACIL Allen, European Southern Observatory (2023).

This is supported by Clarivate analysis, which shows that Australian research in Optical Astrophysics is highly collaborative. The number of Australian research projects involving international collaboration increased from 90% to 92% between the the period before (2013-17) and after (2018-22) the ESO-SP (see Figure 4.8). The size of Australian Optical Astrophysics

[64] Astronomy Australia Limited (2023). Op. cit.

research teams is larger than in the comparator countries and increased over time (see Figure 4.8), which may be considered as an indicator of the level of collaboration occurring.

Figure 4.8 Australian international collaborations and research team size in Optical Astrophysics

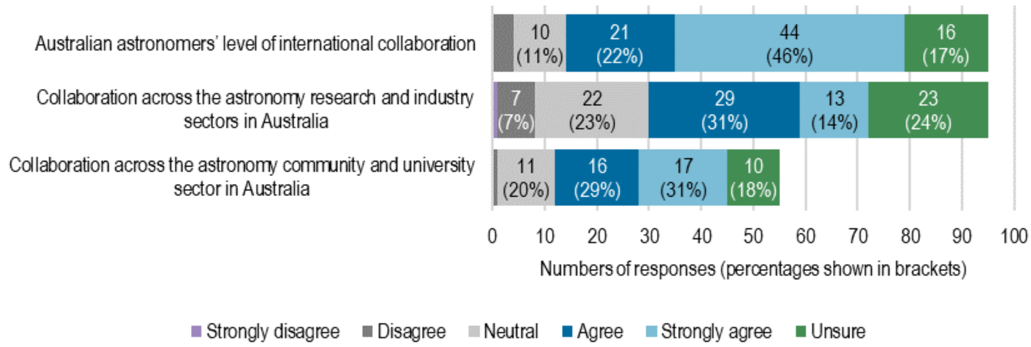


Source: Clarivate

This is supported by the responses to the evaluation survey, which shows that a large proportion of respondents *agreed* or *strongly agreed* that AWLAI had supported Australian astronomers' Australian astronomers' level of international collaboration (67%, see Figure 4.9), and collaboration across the Australian astronomy community and university sector (59%).

Almost half of the survey respondents (45%) *agreed* or *strongly agreed* that AWLAI had improved collaboration across the Australian astronomy research and industry sectors. This is further discussed in section 4.1.2.

Figure 4.9 To what extent do you agree that AWLAI is achieving its intended outcomes of increasing:



n=95

Source: ACIL Allen 2023 Survey of the astronomy sector

Further, the annual Australian ESO User Surveys conducted by ESO from 2019-22 shows that ESO access enabled or fostered new collaborations with astronomers in Australia and ESO member countries, as well as a smaller number of collaborations with other non-ESO members (see Figure C.4).

Collectively, this demonstrates that the ESO-SP has played a role in increasing Australia's collaboration.

To what extent has the ESO-SP generated industry opportunities?

Has Australia's optical astronomy instrumentation capability and commercialisation of astronomy-derived practices, services and technology increased, decreased, or remained the same?

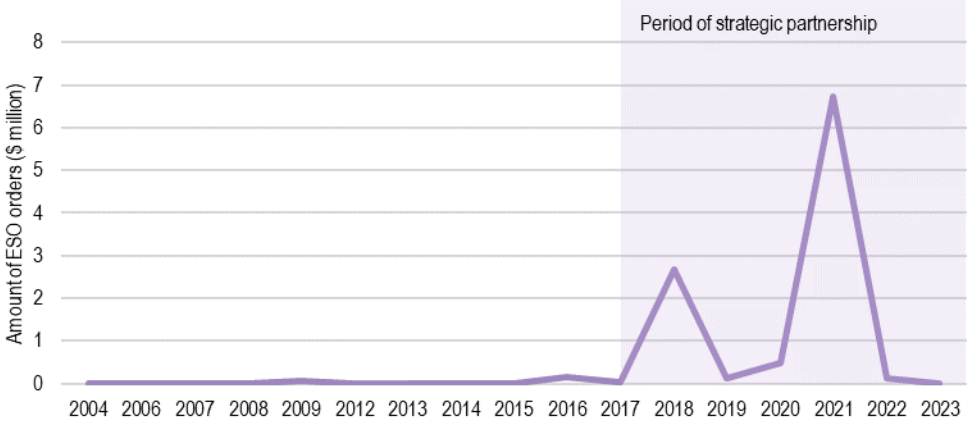
Has the ESO-SP improved Australia's production of astronomical instruments and technology?

4.1.2 Impact of the ESO-SP on industry

The ESO-SP has enabled access to, and award of, commercial tenders in European markets, industry collaborations, and the commercialisation of astronomy technical expertise in other sectors. As a result, some interviewees reported that Australia's optical astronomy instrumentation capability and commercialisation opportunities had increased.

From 2018-22, Australia has received $9.3 million (€6.1 million) in ESO orders for goods and services, including for contracts with non-Australian organisations (see Figure 4.10). Most of the $10.5 million (€6.3 million) returned directly to Australian industry from 2004-22 was returned during the ESO-SP. This demonstrates that the ESO-SP has directly contributed value to industry.

Figure 4.10 Value ($) of ESO orders for goods and services of Australian origin, by year



Source: ACIL Allen, European Southern Observatory (2023).

A total of 35 orders were made, across training (10 orders), light sources, lasers and lamps (2 orders), information technology (2 orders), automated storage systems (2 orders), laboratory equipment (one order) and scientific software (one order). The 3 largest orders represent 90% of the value of all orders made by ESO to Australia.

The largest order was awarded to an international consortium led by Astralis for the procurement of the next flagship VLT instrument, MAVIS (Phase B), in partnership with organisations in Italy and France. This contract is valued at an estimated total of $57 million,[65] with $4.3 million (€2.6 million) provided to Astralis. This leverages Australian capability in large astronomy projects, adaptive optics, and spectrographics. This work has led to ESO exploring whether there is an opportunity to engage Australia on developing HARMONI for the ELT. This is particularly interesting as, in theory, Australia is not eligible to supply services to the ELT. ACIL Allen believes that it illustrates the high regard the ESO has for the strong expertise that Australia has in this technology.

[65] Astronomy Australia Limited (2021) *Agreement signed to build MAVIS, an Australian-led instrumentation project aiming to see further than the Hubble Space Telescope*. Accessed November 2023: https://astronomyaustralia.org.au/blog/news/agreement-signed-by-eso-for-the-construction-of-the-mavis-instrument/

Australia also has a large role in developing a new AESOP 4-metre Multi-Object Spectrograph Telescope (4MOST) important in wide-field surveying, instruments for GMT, and BlueMUSE, a VLT instrument.

Australian Astronomical Optics at Macquarie University was awarded a $5 million, five-year contract to provide services to maintain and develop VLT software pipelines (including Data Reduction Pipelines). Experts from Macquarie University and USYD are providing expertise to improve the way ESO processes the data received by ESO instruments. The ESO-SP enabled the contract to be awarded to an Australian organisation. There is significant potential for Macquarie University to provide further services for the ELT. While this is not currently possible under the ESO-SP, it would be under full membership.

In addition, AAT has purchased 2 next generation controllers from ESO and are collaborating with ESO to build the next iteration of the controllers. This is providing good insights on how to manufacture these controllers in Australia, which could be developed by new companies. These controllers are essential in many ESO instruments. There is also a global market for next generation controllers.

These industry engagements contribute to the Australian Government's priorities in innovation and research collaboration (see section 2.1.1).

Box 4.1 MAVIS at Astralis-AITC

MAVIS is an advanced instrument that will be installed on ESO's VLT in Chile. It uses multiple deformable mirrors and wavefront sensors to compensate for the effects of atmospheric turbulence, allowing for higher-resolution imaging and spectroscopy. This will enable new discoveries across a large portion of the observable sky, from our own planetary system to those around other stars, and from the physics of star formation in the Milky Way to observing high-redshift galaxies in the early Universe with sufficient resolution to reveal significant details of their structural properties and their evolutionary path.

MAVIS is expected to provide substantial improvements in resolution. Indeed, a level of resolution has never been achieved by any astronomical instrument at visible wavelengths. The project is being led by Astralis-AITC (at the ANU), with a Consortium that also includes Astralis-MQ (Macquarie University), INAF (Italy), LAM (France), as well as ESO itself (based in Germany).

In March 2023 the MAVIS Consortium successfully completed the instrument's Preliminary Design Review and has now entered the Final Design phase, which will conclude in December 2024. After the Final Design Review, the actual manufacture and assembly of MAVIS will commence.

Source: Astralis-AITC, accessed on 29 July 2023 at https://rsaa.anu.edu.au/news-events/news/mavis-project-enters-final-design.
Image credit: https://astralis.org.au/projects/eso-mavis/.

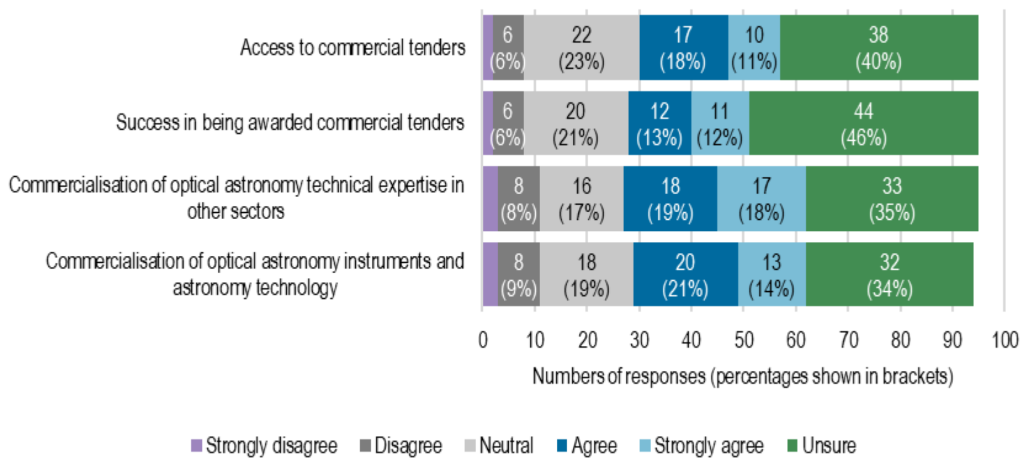
In contrast, many other interviewees reported that AWLAI had not delivered on its objectives of increasing industry engagement due to the limited contractual arrangements set out under the ESO-SP. Some interviewees also reported that Astralis' limited capacity had hindered its ability to meet ESO's infrastructure development needs, and that Astralis could better support these needs with additional staffing resources.

The opportunities available to Australian industry looking to provide services to ESO have also been limited by restrictions to Australia bidding as lead contractors. Prior to the ESO-SP, Australia could collaborate with ESO Members on developing instruments for LPO, but could not lead proposals.[66] Since the ESO-SP, Australian industry can bid directly for work on the VLT, and from 2022 for tenders through the ESO Technology Development Program (focused on developing future technologies for ground-based astronomy in areas such as deformable mirrors, detectors or lasers[67]). Australia can also collaborate with ESO Members on developing instruments for the ELT and ALMA, but cannot lead this work.

In particular, some interviewees reported that Australian industry was well suited to tender for early ELT construction contracts (before the ESO-SP was in place). This includes expertise in remote operations. As a result, some interviewees reported that industry outcomes were limited to Astralis contracts, and to engagement within Europe.

The evaluation survey shows that a large proportion of respondents were unsure of the commercial impacts of AWLAI (34 to 46%, see Figure 4.11). Around a third of survey respondents agreed or strongly agreed that AWLAI had supported the commercialisation of optical astronomy technical expertise in other sectors (37%), commercialisation of optical astronomy instruments and astronomy technology (35%), access to commercial tenders (29%) or success in commercial tenders (25%).

Figure 4.11 To what extent do you agree that AWLAI is achieving its intended outcomes of increasing:



n=95

Source: ACIL Allen 2023 Survey of the astronomy sector

Clarivate citation analysis did not identify significant industry engagement, noting that there are lag times involved in filing of patents. There were no ESO research papers co-authored by Australian industry between 2013-17 and 2018-22, and no identified acknowledgments of industry investment in research. In the comparator countries (UK, France, Japan, Canada) the share of ESO related research papers co-authored by industry is below 2% for all countries. This low level of co-authorship by industry is not unusual in leading-edge discovery research.

Nonetheless, there would be fewer restrictions, and more industry opportunities, if Australia were a full member of ESO. Further, one prominent interviewee suggested that stronger commercial returns would be delivered if the Australian Government took a portfolio approach to astronomy

[66] Ibid.

[67] European Southern Observatory (2022). Op. cit.

(e.g., radio, optical, other). This is discussed further in section 4.1.4. This would allow similar technologies to be applied across different types of astronomy infrastructure (potentially leading to higher quality products being used), and more complex research questions being able to be addressed.

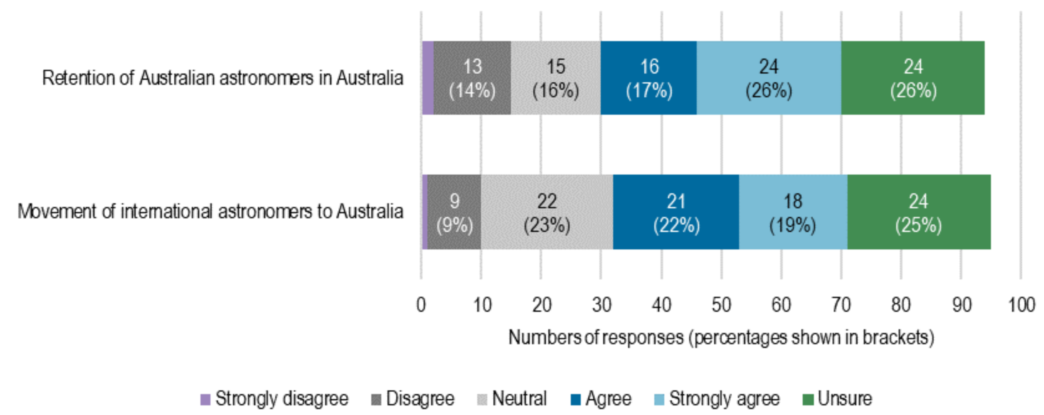
Were ESO-related opportunities sufficiently translated into career benefits for the Australian astronomy community?

4.1.3 Impact of the ESO-SP on career benefits

Many interviewees reported an increase in employment at AAT and Astralis in recent years, mostly at ANU and USYD, due to the positioning of Astralis work packages in the USYD node. Again this was attributed to the hands-on training and work on data analysis across a range of research groups that resulted from the ESO-SP. One interviewee noted that the ESO-SP had provided one university with the confidence to significantly increase the size of its astronomy instrumentation team.

The evaluation survey results show that 43% of respondents agreed or strongly agreed that AWLAI had supported the retention of Australian astronomers or movement of international astronomers to Australia (41%) (see Figure 4.12). However, a large proportion were also unsure or neutral. This suggests that respondents had limited visibility of the impacts of AWLAI across the broader astronomy sector. Many interviewees considered that AWLAI has enabled Australia to attract international researchers to participate in Australian astronomy research. Interviewees attributed this attraction to the ESO-SP.

Figure 4.12 To what extent do you agree that AWLAI is achieving its intended outcomes of increasing:



n=95

Source: ACIL Allen 2023 Survey of the astronomy sector

Students receive training through AWLAI, either through securing observation time or using data obtained from AWLAI program telescopes. For example, the annual Australian ESO User Surveys conducted by ESO from 2019-22 shows that ESO access created benefit for 103 Australian students and 102 postdoctoral fellows through engagement with the data generated by an Australian PI (see Figure C.5).

Astronomy students gain skills in managing large data sets, programming languages, instrument design and development, robotics, industry practice and project management. These skills are in strong demand by industry. Astronomy graduates have progressed to work in academia, industry, the health sector and government.[68]

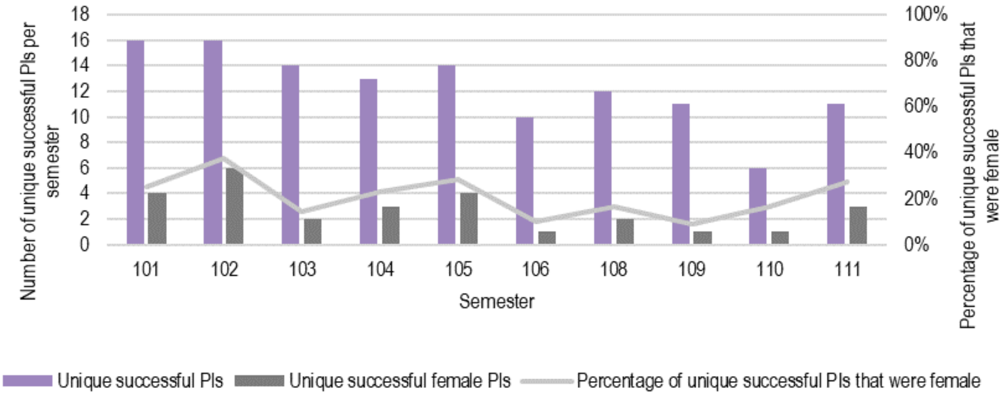
[68] Australian Academy of Science (2015). Op. cit.

Some interviewees reported engagement of younger Australian researchers with ESO, this includes Large Programs led by early/mid-career scientists, rather than these programs being traditionally led by late-stage career scientists. Further, USYD operates a successful PhD and internship program, which includes astronomy students among a diverse range of disciplines. This is being implemented in other Astralis nodes.

There are also opportunities for further engagement in ESO-based internships and fellowships to embed international collaboration and build the capability of Australia's astronomy research sector, and to strengthen collaboration between Astralis universities and industry partners. For example, the ESO Fellowship Programme provides an opportunity for young researchers to be supported in their transition to independent scientists, through working with observing sites in Germany or Chile.[69] More than 10 Australian students and academics have spent between 3 and 24 months visiting ESO Headquarters in Germany and Chile for scientific exchanges. Further, a total of 24 researchers travelled from Australia to Chile to work with international researchers and conduct hands-on observations with ESO telescopes. These numbers would likely be higher in the absence of COVID-19 pandemic restrictions.[70]

ESO collects data on the gender balance of unique successful PIs using ESO facilities. In total, 22% of unique successful PIs were women, varying from 9% to 39% in each semester. However, there is no clear trend over time in the data (see Figure 4.13). This aligns with the findings reported in the Decadal Plan, which cited the need for greater representation of women in the astronomy industry, with women consisting of only 20% of all roles.[71] The proportion of Australian female successful PIs (22%) is below previous records of ESO's female PI rate of approximately 30% across all member nations.[72]

Figure 4.13 Proportion of all unique successful PIs by gender balance and ESO by semester



Source: ESO

[69] European Southern Observatory (2023). *Fellowships in Germany or Chile*. Accessed January 2024: https://www.eso.org/sci/activities/fellowships-and-studentships/FeSt-overview/fellowship_programme.html.

[70] Ibid.

[71] Australian Academy of Science (2015). Op. cit.

[72] Patat, F. (2016). *Gender systematics in telescope time allocation at ESO*. arXiv preprint arXiv:1610.00920.

4.1.4 Synergies between ESO, AAT and SKA precursors

Several interviewees and survey respondents identified synergies between ESO, AAT and SKA precursors. The evaluation survey showed that across respondents receiving time on both ESO and AAT, 42% reported that *access to AAT has improved their success in applying for ESO facility access* (see Figure B.20). Survey respondents reported that this was because AAT's data and findings are an important foundation for ESO-based research (see Figure B.21).

Further, of the ESO papers published with Australian researchers (see Figure 4.4), 21% include data from ESO and Australian SKA precursor telescopes, that is, the ASKAP and MWA. This highlights the synergy between Australia's investments in the SKA and the ESO-SP.[73] Further, 25% of evaluation survey respondents had accessed both facilities. Of these, 7 of 17 qualitative responses identified *significant synergies* from accessing both facilities, 4 reported that *using both facilities is/will be very important*, and 4 reported that *both facilities have been essential for their research* (see Figure B.24).

Further, while most (75%) survey respondents had not received time on SKA precursor telescopes (see Figure B.22), the small number that did, reported synergies between the facilities that benefited their research (see Figure B.23).

Access to both world-class radio and optical astronomy facilities is increasing and is likely to continue to increase the complexity of the research that can be undertaken by Australian researchers, and the potential impact of the research discoveries that may be made and led by Australian researchers.

Some interviewees considered that there was, and remains, an opportunity to better leverage synergies between these capabilities by taking a portfolio-based approach to astronomy in Australia. This could include longer term strategic planning for access to radio and optical astronomy research infrastructure, and financial support for both forms of astronomy.

An example of synergies between the use of optical and radio telescopes is provided in Box 4.2.

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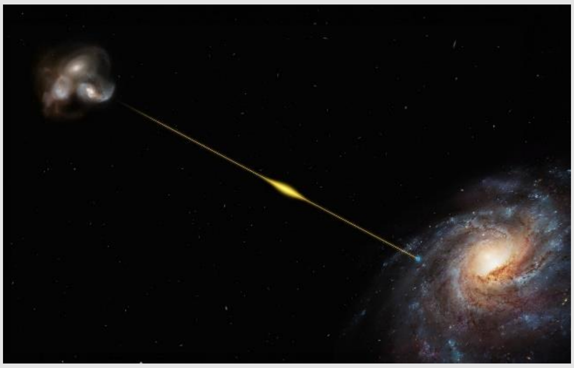
[73] European Southern Observatory (2023). Op. cit.

Box 4.2 Synergies between radio and optical astronomy – Fast Radio Bursts

Fast radio bursts (FRBs) are brief flashes of radio emission from extragalactic sources. In June 2022, Australian researchers using ASKAP detected a FRB that is thought to be the most distant ever found.

The researchers used one of the world's most powerful optical observatories (ESO's VLT in Chile) to search for the host galaxy. The ESO's telescopes are equipped with cutting-edge cameras and spectrographs that can identify faint host galaxies and study their properties in detail.

At the position pinpointed by ASKAP as the source of the burst, initial images revealed faint smudges of light that looked like a distant galaxy. Analysing the spectrum of light from the galaxy showed it was strongly "redshifted", meaning the emission from the burst had doubled in wavelength as it stretched out on its journey through the expanding universe.



The redshift had a value just over 1, which shows that the burst was emitted more than 8 billion years ago, when the universe was less than half its present age. This confirmed that FRB detected had broken the record for the most distant fast radio burst.

The researchers argue that the discovery demonstrates the potential for FRBs to study the composition of the distant universe. This would only have been possible through the use of both radio and optical astronomy facilities and expertise.

Source: S.D. Ryder et. al. Science, 19 Oct 2023, Vol 382, Issue 6668, pp. 294-299, DOI: 10.1126/science.adf2678.

Image credit: https://www.sydney.edu.au/news-opinion/news/2023/10/20/australian-scientists-detect-most-distant-fast-radio-burst-ever-.html#:~:text=This%20'fast%20radio%20burst'%20(,distance%20record%20by%2050%20percent.

Would the research output, impact, and productivity of the Australian Astronomy community be reduced without access to ESO Facilities? If so, do alternate approaches exist to ensure no loss of output, impact, and productivity?

4.1.5 Impact of loss of ESO Facility access on research output, impact, and productivity

All interviewees and most survey respondents strongly considered that the research output, impact, and productivity of the Australian astronomy community would be reduced without access to ESO facilities (further discussed in section 5.1.3). They reported that there was no viable alternative that could maintain Australia's astronomy impact and international research standing (discussed in section 2.1.2). Researchers would still have access to some limited facilities (e.g. ALMA, see section 4.1.1) under ESO's Open Skies policy.

This is supported by survey data which shows that out of 46 respondents, in the absence of access to ESO facilities, 60% reported no realistic alternative as their research could only be completed with ESO, 37% would change their research focus, and 35% would work with international collaborators (see Figure B.6). Of those that unsuccessfully applied for observing time on ESO facilities, 58% reported that they were intending to reapply (see Figure B.7).

Some interviewees reported that loss of access to the facilities available through the ESO-SP would also hinder research in radio astronomy, as there is a growing focus on multiwavelength research and a need to cross-validate between the observation made using optical and radio telescopes around the world (see Box 4.2). This lends support to the argument that a portfolio approach to astronomy would be desirable.

4.2 Outcomes and impacts of AAT

Key Finding 7 Outcomes and impacts of AAT

> The research sector's access to the AAT reduced somewhat following the transfer. This was reportedly due to restrictions on non-AAT Consortium universities and the need to sell time to international researchers to help fund the telescope's operational costs.
>
> However, despite these factors somewhat reducing access, most survey respondents reported that the quality of research produced using the AAT largely remained the same during the transfer of AAT to the AAT Consortium, with growth in the number of publications and Australian research contribution to the AAT.
>
> The impact of Australian research using the AAT remained the same and is above world average.

Has access to the AAT increased, decreased, or remained the same for domestic astronomers?

4.2.1 Access to the AAT for domestic astronomers

As noted in section 3.2, the research sector's access to the AAT was reduced following the transfer of the telescope to the AAT Consortium.

The AAT observation time allocation process did not change during the transfer. This is positive, as 70-90% of survey respondents that had applied for access to AAT *agreed* or *strongly agreed* that the processes (i.e. reporting, feedback on applications, the online submission platform, application form and program guidelines) for accessing AAT facilities were clear and easy to follow (see Figure B.16). For example, 90% of survey respondents found that the application forms were clear and easy to follow.

Researchers have continued to focus on larger programs that require multiple nights of observing time. This aligns with AAT's strengths as a survey instrument. The AAT has also been a key facility for training domestic students in optical astronomy. On average, student-led proposals requested 40 nights per semester (14% of total nights requested).[74]

However, the total observation time and pool of potential recipients reduced when AAT transitioned from an open access model (with applications assessed on the basis of excellence of the proposed research) to allocating time only to the 13 (then 11) member universities. These universities receive allocations of observing time proportional to their respective financial contributions. Members decide whether to allocate observation time based on projects or donate it to a pool that is distributed based on merit to all members of the consortium.

While these universities cover most of the Australian astronomy community, the researchers excluded are significant. For example, one interviewee noted that Western Australian researchers were heavy users of AAT, yet lost access during the transfer.

Since transitioning to the AAT Consortium, a proportion of AAT observation time is also allocated for sale to international researchers. While this is necessary to raise funds for the operation of AAT (see section 1.2), it reduces the observation time available for Australian researchers. The number of nights sold on AAT has increased since 1 July 2018 (see Figure 4.14). From the second semester of 2018 (10 nights) and the first semester of 2019 (3 nights), the number of nights sold increased to a peak of 25 nights (15% of nights) in the first half of 2022 and second half of 2023. Projections of nights sold in upcoming semesters highlights a continuing demand for use of AAT. This has generated approximately $530,000 per year in revenue.[75]

[74] AAT Review Final Report

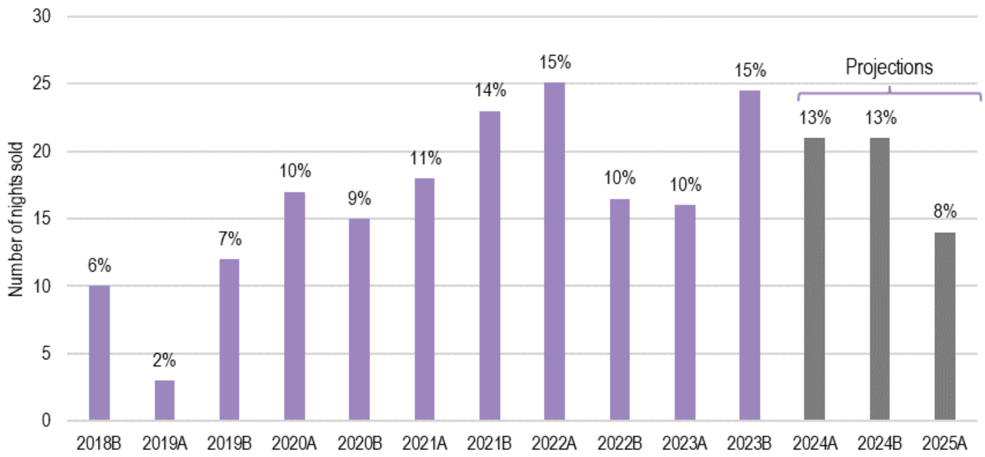
[75] Astronomy Australia Limited (2023). Op. cit.

This is supported by the evaluation survey, which shows that 32% of respondents reported that overall access to AAT decreased following the transition of the AAO to the AAT Consortium, and 20% of respondents' personal access reduced (see Figure B.19).

This is particularly important, as 40% of survey respondents reported that without access to AAT, they had no realistic alternative as their research could only be completed using the AAT. However, 21% would try to access other instruments (see Figure B.13).

Collectively, this highlights the value researchers place on access to AAT, and that this access has reduced since the transition of the AAO to the AAT Consortium.

Figure 4.14 Number of AAT nights sold, and percentage of total nights (by semesters)



Note: years are divided into 2 semesters, represented as semester A and B.

Source: ACIL Allen, AAT

Has the quality and impact of AAT research increased, decreased, or remained the same?

4.2.2 Quality and impact of AAT research

Overall, some interviews reported that the quality and impact of AAT research did not change substantially **during** the transfer of AAT to the AAT Consortium.

Interviews and the evaluation survey asked whether the quality and impact of AAT research changed **after** the transfer. Some interviewees reported that AAT remains a high-quality facility that continues to deliver valuable scientific output. It is also oversubscribed and is effective in observing across time, enabling large surveys and follow up on data gained from other facilities, and in filling the gap between what telescopes in South Africa and Chile can observe. As such, AAT remains important in supporting quality and impactful research (discussed further in section 5.2).

Most survey respondents reported that transferring the AAT to the AAT Consortium did not change:

— the impact of their AAT research (66% said it remained the same, 10% said it decreased)

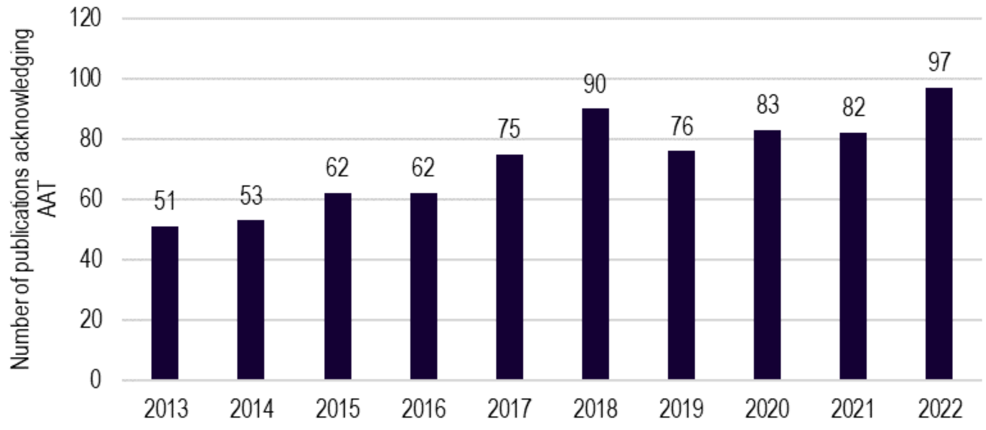
— the quality of their AAT research (52% said it remained the same, 12% said it decreased)

— their access to the AAT (66% said it remained the same or increased, 20% said it decreased) (see Figure B.19).

However, some survey respondents reported that the overall quality (20%) and impact (16%) of AAT research reduced after the transfer of the AAT to the AAT Consortium (see Figure B.19). In comparison, Clarivate analysis shows that the number of papers referencing AAT increased by 4% between 2013-17 (47.6 scientific publications) and 2018-22 (49.4 scientific publications). This growth rate is above the global average for Optical Astrophysics, which grew by 1% over the same period. The number of papers published grew from 51 in 2013, to 90 in 2018 and 97 in 2022 (see Figure 4.15). The impact of these papers remained the same between the periods and is above world average and comparable to the comparator countries (i.e. the UK, Japan, France and Canada).

Australian research contribution to the AAT, that is, the level of effort contributed to projects (a measure of the number of authors and investment in a paper) increased by 4% between the periods 2013-17 and 2018-22. Further, the impact of Australian research using the AAT remained the same between the periods. The impact is above the world average and similar to the comparator countries.

Figure 4.15 Number of publications acknowledging AAT, by year



Source: Clarivate

Survey respondents were asked to identify the factors that had helped, or could help, achieve AWLAI outcomes (see Figure B.37). Survey respondents most commonly reported that *continued access to ESO (and expansion to ELT)* (50%) and *certainty regarding future partnerships and access* (15%). This is supported by several interviewees, who noted that that having more certainty on Australia's future participation in ESO would be desirable. Further, survey respondents commonly reported that the *loss of* access to ESO has or is most likely to hinder the achievement of AWLAI program outcomes (55%, see Figure B.38).

Collectively, this suggests that the changes associated with the AWLAI program have been bedded down over recent years and are delivering value to the astronomy community.

4.3 Broader benefits from astronomy research

Key Finding 8 Broader benefits from astronomy research

> Engagement in astronomy has delivered benefits to other sectors. This has occurred through the movement of skilled personnel from astronomy research and industry to other high-value industries, as well as spillovers of technology from astronomy to other fields.
>
> This supports a range of Australian Government broader strategic priorities.

The broader benefits of astronomy research are varied, numerous and challenging to quantify and attribute to any individual piece of research or initiative. Several examples of benefits from astronomy research are discussed below. While it is difficult to attribute these specifically to AWLAI, it is likely that the program has contributed substantially to Australia's broader capability in astronomy, and has thus supported the delivery of these benefits, many of which will only emerge in the long term. For example, CSIRO first developed WiFi in 1992,[76] with a major commercial breakthrough only realised in 1999 when adopted by Apple Inc in Apple products.[77] WiFi is still being developed and adopted to date.

This is further demonstrated by the 2021 United States National Academies of Sciences report, which concluded that:

> *The social benefits of investment in astronomy extend far beyond astronomy itself. This contribution is of particular importance in contributing to a technically trained STEM workforce. Students with college-level training in astronomy and physics can access an extraordinarily broad range of technical careers—from education to national security to commercial R&D and beyond —that help fuel and sustain the nation's global leadership and well-being. Astronomical discoveries inspire people to pursue STEM careers generally, not only in astronomy.*[78]

> *Astronomy research continues to offer significant benefits to the nation beyond astronomical discoveries. These discoveries capture the public's attention, foster general science literacy and proficiency, promote public perception of the value, legitimacy, and integrity of science, and serve as an inspirational gateway to science, technology, engineering, and mathematics careers.*[79]

Many interviewees identified several broader benefits from astronomy research, which align with (as discussed in section 2.1.1) and support the Australian Government's strategic priorities. This includes Australia's National Science and Research Priorities, skilled workforce, and STEM priorities.

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[76] Sibthorpe, C. (2018). *CSIRO Wi-Fi invention to feature in upcoming exhibition at National Museum of Australia*. Accessed January 2024: https://www.canberratimes.com.au/story/6045947/csiro-wi-fi-invention-to-feature-in-upcoming-exhibition-at-national-museum-of-australia/.

[77] Hetting, C. (2018). *How a 1998 meeting with Steve Jobs gave birth to Wi-Fi*. Accessed January 2024: https://wifinowglobal.com/news-and-blog/how-a-meeting-with-steve-jobs-in-1998-gave-birth-to-wi-fi/.

[78] US National Academies of Sciences, Pathways to Discovery in Astronomy and Astrophysics for the 2020s, 2021, accessed on 30 July 2023 at https://nap.nationalacademies.org/catalog/26141/pathways-to-discovery-in-astronomy-and-astrophysics-for-the-2020s

[79] Ibid.

4.3.1 Innovation and technology transfers

Many interviewees reported significant instances of technologies being developed for, and adapted from, the astronomy sector to a broader range of applications and industries. Without the ESO-SP, it is unlikely that Astralis would have had the opportunity to develop such technologies for use beyond the astronomy sector. This has been facilitated largely by the AITC, a node of Astralis operated by ANU, and the AAO Astralis node operated by Macquarie University (see Box 4.3).

Box 4.3 Examples of Astralis and AITC nodes developing and adapting optical astronomy technologies for broader uses

From Astralis (AAO, Macquarie University):

- **LIDAR system for moon lander**: To be built by Australian company Advanced Navigation and flown on NASA moon lander. Optical system to be designed, manufactured, and tested by AAO.
- **Thermal Imager for Gilmour Space**: Rapid development and space qualification of Thermal Imager operating at long-wave infrared by AAO. To be flown by Australian company Gilmour Space in 2024.
- **NSW Defence Innovation Network award**: research and development at AAO for targeting a system at imaging moving satellites from a space-borne platform.
- **Multi-object Raman spectrometer for biological samples**: Spectroscopy has been used to identify sex of insect eggs and pupae. AAO is developing a multiplexing system allowing multi-million sample sorting in acceptable timeframes, in partnership with Applied Biosciences at Macquarie University. A patent application is under review.

From Astralis (AITC, ANU):

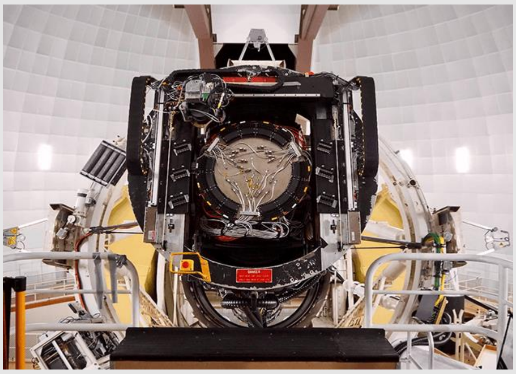
- **Real-Time Computers**: High throughput (TFlops), low latency (100 microseconds) computers have been developed and used for adaptive optics applications. This could be extended to other real time critical tasks/disciplines. Three have been sold worldwide (US, Germany, Italy) or are under construction (in association with microgate Italy and Swinburne University). This project has been funded through NCRIS/AAL.
- **Deep space laser communication**: Funded by the Australian Space Agency, this project has demonstrated laser communications with Mars. This has a high potential for technology transfer to industry.
- **Hyperspectral imaging, earth observations**: This imaging capability can predict bushfire threats from space. This project has been funded by SmartSAT CRC.
- **Detector controllers and subsystems**:
  - Rosella: Funded by the *Moon to Mars Initiative: Trailblazer*. It is a rugged detector controller that is designed for space missions.
  - Cryo controllers are being developed for ESO's New Generation Controller II, components sold to ESO. Funded by ARC.

Source: Personal communication with AAL.

Image credit: https://aao.org.au/2023/01/15/aao-to-build-thermal-imager-for-gilmour-space/#:~:text=As%20part%20of%20this%20new,for%20launch%20in%20late%202023.

Box 4.4 outlines an example of a partnership generated from the development of a new instrument for AAT. This partnership between Astralis and watch manufacturing company Nicholas Hacko Watchmaker, improved industry capabilities within astronomy and precision manufacturing sectors.

Box 4.4 The Hector Instrument



Astralis Consortium required precision manufacturing capabilities for a multi-Integral Field Unit spectrograph (called Hector) produced for AAT. Astralis partnered with a watch manufacturing company (Nicholas Hacko Watchmaker), which assisted Astralis in manufacturing parts with precision of 20 50 µm. The company worked with Astralis to craft components valued at hundreds-of-thousands of dollars.

The company have since applied this capability to expand into precise medical instrument manufacturing, operating under the spin out company NHMicro.

The partnership has been mutually beneficial, improving Astralis' capabilities, and opening a new line of business

Source: Astronomy Australia Limited (2022) The Hector Instrument.
Image credit: https://astralis.org.au/hector-first-light/.

Further, a 2013 Canadian report noted that:

> *The associated challenges to design and build powerful and sensitive instruments for new telescopes also drive technological and industrial developments that see a vast realm of applications in large and sophisticated steel structures, in advanced optics, digital cameras, medical imaging, ophthalmology, GPSs, and so on.*[80]

While many specific examples have been well reported, including CSIRO's invention of WiFi through radio astronomy research, others include:

— Astronomy researchers use adaptive optics to adjust for distortion created by the atmosphere (using lasers) and thus enhance the quality of data obtained from telescopes. ANU received a $6.2 million grant from the Australian Space Agency to research the translation of this technology beyond astronomy. For example, the same technology can be used to improve satellite communication (making communications with satellites faster and more secure).

— Fibre optics research for astronomy in the 1980s led to the use of micro-robotics in medicine.

— Development of ground-based sensing systems for cube satellites, which are used to gather information about the trajectory of CubeSats as they orbit.

— Developments in multi-object spectroscopy for astronomy has proved important in applied biosciences in identifying the sex of mosquito eggs and developing sterile mosquito release methods to control populations.

— New digitised systems for timely data analysis were developed to analyse the signals that identified fast radio bursts on the Parkes radio telescope. This discovery was recognised with

[80] Association of Canadian Universities for Research in Astronomy, 2013, The Thirty Meter Telescope and Astronomy in Canada, accessed on 29 July 2023 at https://casca.ca/wp-content/uploads/2013/10/NRC_TMT_report_Aug2013.pdf

the Shaw Prize in Astronomy,[81] an international award to honour distinguished and significant advances, and outstanding contributions in academic and scientific research and applications. The fast radio bursts are being validated and better understood through ESO's optical astronomy instruments.

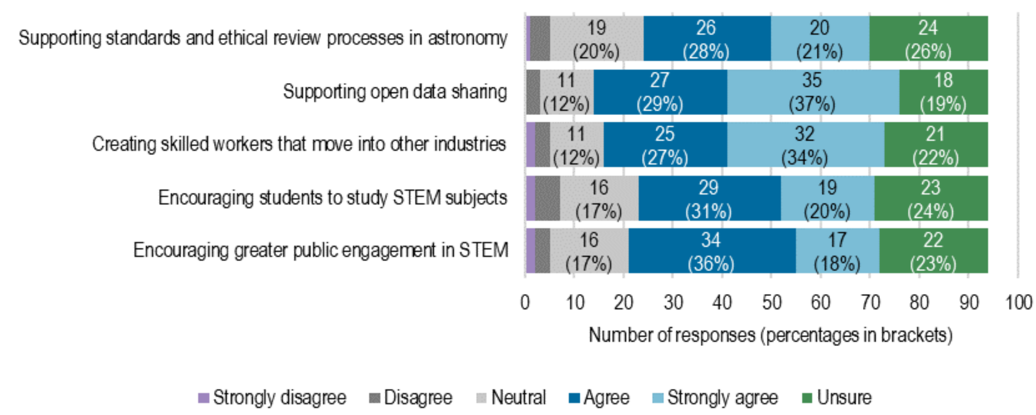
— Phased Array Feed technology developed by CSIRO for use in radio astronomy was commercialised by Australian start-up Quasar Satellite Technologies (QuasarSat) to improve satellite communications with ground stations. This has the capability to simultaneously monitor and communicate with hundreds of satellites and enable real-time satellite data to be securely provided to a range of end-users.[82]

4.3.2 Skills development and transfers

Astronomy researchers' skills include software development, management and analysis of large datasets, image processing and analysis, statistics, and mechatronics. Many interviewees considered that the skills astronomers develop are highly sought after by a range of high-value industries. This has allowed people to easily move from the astronomy research sector to other industry sectors.

Examples of astronomy researchers moving into other fields in Australia include in the Civil Aviation Authority, Square, Geoscience Australia, the Murray-Darling Basin Authority, the financial sector, high tech optical companies, software engineering and the medical sector. The survey results support this with 61% of respondents either *agreeing* or *strongly agreeing* that AWLAI is creating skilled workers that move into other industries (see Figure 4.16).

Figure 4.16 To what extent do you agree that AWLAI is supporting other benefits, including:



n=94
Source: ACIL Allen 2023 Survey of the astronomy sector

For example, the Decadal Plan reports that at least 50% of astronomy PhDs between 2010-14 had jobs in astronomy, and at least 30% had moved into other fields of work (20% were unknown). Of those working in other fields, 50% were in information technology or analytics, 30% in other research or scientific disciplines, and 20% in a range of other sectors (e.g., teaching, tech, finance).[83]

[81] Australia Telescope National Facility (2023). *Astronomers win Shaw Prize for fast radio burst discovery*. Accessed September 2023: https://www.atnf.csiro.au/news/news.php?action=show_item&item_id=1941.

[82] Astronomy Australia Limited (2022). *Dr Ilana Feain – QuasarSat*. Accessed October 2023: https://astronomyaustralia.org.au/industry-engagement/ilana-feain-quasarsat/.

[83] Australian Academy of Science (2020). Op. cit.

Further, several interviewees reported that astronomy research has a substantial impact on children's interests in STEM. This supports student engagement in STEM education and development of the STEM skills pipeline. Some interviewees considered that without investment in astronomy research through AWLAI, there would be less engagement and public outreach that would draw students into STEM. This is recognised in the Decadal Plan, which states "Astronomy is a successful vehicle for promoting engagement with, and attracting students into the science, technology, engineering and mathematics (STEM) disciplines".[84] Astronomy as a gateway science is supported by the evaluation survey, which showed that respondents report that AWLAI is supporting other benefits, including encouraging greater public engagement in STEM (54%) and students to study STEM (51%) (see Figure 4.16).

This aligns with the Australian Government's priorities in attracting scientific experts to Australia and developing a skilled labour market (see section 2.1.1).

Some interviewees reported that bold new discoveries and findings could be made more visible and engaging to the public and students to support a pipeline of future STEM students and workers.

What, if any, unintended consequences have there been, positive and negative, and for whom?

What factors (internal and external) are helping and hindering the achievement of intended outcomes, or are likely to do so?

4.4 Unexpected outcomes from the program

Key Finding 9 Unintended consequences from the program

AWLAI has resulted in some negative unintended consequences, including funding constraints and challenges transitioning from AAO. While there have been challenges in establishing both the AAT Consortium and Astralis, stakeholders largely reported that these organisations have both strengthened and matured over time.

Despite the issues noted above, AWLAI is delivering value to the astronomy community.

Stakeholders stated that more certainty on future participation in ESO would be desirable.

Some interviewees identified unintended consequences resulting from AWLAI. These included negative unintended consequences, such as funding constraints, job uncertainty and staff turnover at AAL, AAT and Astralis, and the challenges transitioning AAO to the university sector (discussed in section 3.1.3). This may have slowed the achievement of some AWLAI program outcomes and reduced the effectiveness and efficiency of these organisations. Over time, these arrangements have embedded and become more efficient and effective. However, there remain opportunities to create funding certainty to ensure more strategic and longer-term planning can be conducted.

[84] Australian Academy of Science (2015). Op. cit.

Future opportunities 5

This chapter provides the findings of the evaluation regarding future opportunities for key AWLAI program components.

5.1 Impacts of acceding to the ESO Convention

Key Finding 10 Impacts of acceding to the ESO Convention

Prior to accession, Australia would need to consider the costs and potential benefits of future membership.

Acceding to the ESO Convention would provide long term stability for the astronomy community, ensure increased access to world-class facilities, help maintain Australia's research excellence, and enhance the existing contracting opportunities. If Australia decides to pursue accession, the benefits would likely increase due to increased access to facilities and tendering opportunities. Bringing the accession date forward would bring forward these impacts.

The ESO-SP is time limited. If Australia does not accede it will lose direct access to ESO facilities. While Australian astronomers may continue to access ESO facilities by partnering in research projects led by other countries, they could only lead projects that were awarded under ESO's Open Skies policy (which provide limited access). Australian companies would also lose any potential to tender for industry contracts. This would reduce Australia's current astronomy outcomes and forgo the potential outcomes that would be available under full membership.

Whole-of-Government priorities continue to justify involvement in ESO, noting that the Australian Government is in the process of refreshing the National Science and Research Priorities. Any future decision on whether to fund full membership of the ESO will be made based on the government's objectives and priorities at the time.

Would Australian benefits from the ESO-SP be likely to be increased, reduced, or unaffected by accession to the ESO Convention prior to the end of the ESO-SP?

5.1.1 Benefits to Australia from acceding to the ESO Convention

Most interviewees considered that acceding to the ESO Convention would provide long term stability for the astronomy community, by ensuring secure access to world-class facilities. Interviewees reported that this stability is essential in attracting, retaining, and developing the research and industry expertise in Australia, and in maintaining Australia's research excellence. This is particularly the case as the bulk of Australia's allocated observing time is for Large Programs over multiple years, and as the end of the ESO-SP approaches researchers will be hesitant about starting such longer term projects.

Further, ESO has a 'just retour' approach on contracts, so in principle, countries should receive benefits back from ESO that are roughly equal to the amount they contribute to the organisation. As Australia currently only receives access to the La Silla and Paranal Observatories compared to the full suite of facilities available to full members, acceding to ESO would:

— increase the amount of guaranteed observing time returned to Australian researchers
— allow access to a wider range of instruments such as ELT and ALMA (see section 4.1.1)
— allow participation in industry contracting opportunities through ESO's 'fair return' policy in the instrumentation R&D program and enable industry to engage in contracts for ELT instruments and ALMA, and to work on future technologies.
— provide Australia with more understanding and visibility of ESO's direction and future opportunities, and a say in strategic decisions, rather than having a purely observer role.
— enable Australian researchers to lead collaborations with international researchers on a wider range of ESO instruments.

Some interviewees noted that the ESO-SP has provided an excellent short-term solution for Australian optical astronomy researchers to access world class infrastructure, and provided a useful bridge toward full ESO membership. This has included providing the mechanism for the Australian astronomy community to integrate into ESO, ensuring that the Australian astronomy community can quickly leverage the additional benefits enabled through full ESO membership. However, there was general recognition across all interviewees that the ESO-SP is time limited, and more work is needed to develop a long-term plan.

Most interviewees broadly supported early accession and highlighted that additional advantages could have been realised had Australia joined ESO earlier (i.e., access to ELT contracts and ALMA).

If accession occurred prior to the end of the ESO-SP, then a portion of the payments committed under the ESO-SP could be used to offset the costs of the ESO membership fee. Australia's access to key facilities and contracting would also increase sooner, allowing research and industry benefits to emerge earlier. This would also be beneficial for ESO, as ELT construction has been slowed by funding shortages. As such, Australia's membership fees would likely contribute to construction of the ELT. There could also be more possibilities for Australian industry to win contracts related to the construction of the ELT given the construction delays. However, this will also likely delay access to ELT.

However, most interviewees recognised that there needed to be an appetite, and financial willingness, for joining ESO within the Australian Government if Australia is to accede, and particularly to accede prior to the end of the ESO-SP.

Many interviewees noted the risks of delays to accession given the negotiation period could be lengthy, as evidenced by the lengthy period of negotiation for similar arrangements. This could be further exacerbated by Australian Government elections between now and the end of the ESO-SP. As such, several interviewees emphasised the importance of negotiations beginning as soon as possible if Australia is to transition from the ESO-SP to full membership in a timely manner.

Would an extension of the current ESO-SP beyond 2027, rather than accession to full membership, result in continued delivery of current astronomy outcomes?

5.1.2 Extending the current ESO-SP beyond 2027

Most interviewees strongly considered that extension of the current ESO-SP beyond 2027, rather than accession to full membership, was not an option.

Some interviewees reported that ESO may continue to accept a small contribution for Australia's participation. However, they also noted that would not be ESO's preference. Others reported that an extension of the ESO-SP would only be possible if this was a short-term arrangement that was directly linked with a clear transition to full membership. This could be used to address any gaps in ESO access that could result from potentially lengthy negotiations.

While it is possible that the current access to ESO would be maintained through an extension of the SP - including the restricted access to contracting opportunities, there is no guarantee of this access or continuation of contracting opportunities.

If such an extension was made (with continued access and contracting opportunities), with a pathway to full membership in place, it could ensure that Australian researchers retain access to ESO and therefore the continued delivery of current outcomes (see chapter 4). However, these outcomes would likely be maintained at current levels and with current limitations (see section 4.1.2). This includes restricted access to industry contracting opportunities, notably including ELT contracts. In contrast, if Australia acceded to the ESO Convention before the ESO-SP expired, industry would have increased opportunities from the date of accession.

Are there any risks to failing to accede to the ESO Convention in a timely fashion (i.e., if there is a gap between the end of the ESO-SP and accession as full members)

5.1.3 Consequences of not acceding to the ESO Convention

All interviewees considered that there were significant consequences of not acceding to the ESO Convention. These include that Australian researchers could only lead research projects awarded under ESO's Open Skies policy (which are limited in the available observing time and ESO's policy of awarding observing time to member states where member state and non-member state proposals are equally rated) or participate as part of collaborations. Further, there would be no opportunities for industry to directly contract with ESO. This would limit the potential benefits of the ESO to Australia's astronomy research community and Australian industry.

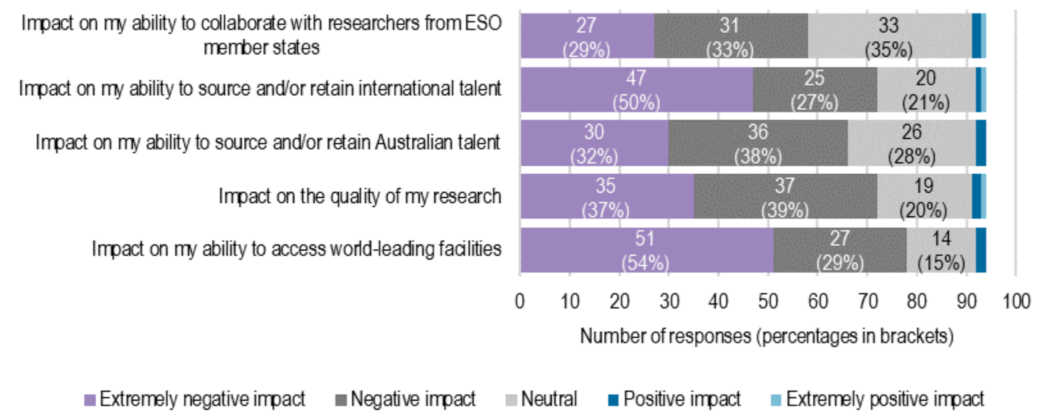
If Australia decided not to join ESO then researchers could still bid for observing time on ESO facilities as part of collaborations. However, the time that would be available to Australian researchers would likely be significantly less than is currently the case, as evidenced by an increase in observing time from an average of 222 to 970 hours per semester following the execution of the ESO-SP (see section 4.1.1).

This would reduce Australia's current astronomy outcomes (described in chapter 4), and the potential outcomes that would be available under full membership (e.g., access to a broader range of facilities and industry contracts).

This view is supported by the evaluation survey, which shows that the impacts of not acceding to full ESO membership would have an *extremely negative impact* or *negative impact* on respondents (see Figure 5.1), particularly their ability to access world-leading facilities (83%), to source and/or retain international talent (77%) and the quality of their research (77%).

In the concluding remarks for the survey, respondents most commonly reported that *losing ESO would have a very negative impact* (50%, see Figure B.39) and that it is essential to their research or organisation. However, it should be noted that 22% suggested that government should consider other options for investing in astronomy, such as prioritisation of funding for Australian entities like Astralis, and access to other telescopes, such as the GMT.

Figure 5.1 What are the implications of not acceding to full ESO membership (noting that the strategic partnership cannot be extended)?



n=94
Source: ACIL Allen 2023 Survey of the astronomy sector

Further, some interviewees reported that in the absence of any indications of whether Australia would proceed to full ESO membership, Australian researchers would need to begin making alternate plans to access astronomy facilities. However, such arrangements are difficult to negotiate, and it would take researchers many years to start securing access to these facilities as these options are individually negotiated and observing time is pre-planned across multiple years.

Collectively, this suggests that there are potentially significant consequences for Australian astronomy research of not acceding to the ESO Convention.

How has the current global financial situation and COVID pandemic affected the business case for ESO Membership?

5.1.4 Impact of the current global financial situation and COVID-19 pandemic on the business case for ESO Membership

The global financial situation and COVID-19 pandemic have not changed the astronomy community's desire for ESO Membership.

Some interviewees reported that the COVID-19 pandemic created travel restrictions that impacted easy, in-person attendance at ESO facilities. However, they did not identify any ongoing impacts from the COVID-19 pandemic.

Some interviewees also recognised that, at the time of interviews, the global economic situation may limit the funding available for accession to ESO. However, it should be recognised that if Australia decide to accede to ESO, then this would align with a broader global trend towards multinational involvement in large-scale research infrastructure, as reflected in the Decadal Plan.[85]

Any future decision on whether to fund full membership of the ESO will be made based on the government's objectives and priorities at the time.

Do whole-of-Government priorities continue to justify the Commonwealth involvement in ESO?

5.1.5 Continued need for involvement in ESO

The whole-of-Government priorities at the time of finalising this report (noting that the Science and Research priorities are currently being refreshed) align with Australia's current and potential future involvement with ESO.

Australia's draft National Science and Research Priorities were released for consultation in September 2023.[86] The draft priorities did not specifically refer to astronomy research, however ACIL Allen did not identify any elements in the draft priorities that would preclude Australia from acceding to ESO. The aims outlined in *Priority 3: Enabling a productive and innovative economy*, align with the potential opportunities available through ESO membership, including, to "*build new industries and accelerate productivity by having sovereign knowledge and access to develop and harness impactful emerging technologies*" and "*engage in more research and development increasing our global competitiveness*".[87] The Australian Government is also refreshing Australia's National Science Statement, which was published in 2017.[88]

The 2021 National Research Infrastructure Roadmap (2021 Roadmap) has replaced the 2016 Roadmap. The 2021 Roadmap retains astronomy as a priority area, stating that astronomy research should be underpinned by research infrastructure, including:

> *Optical and radio astronomy infrastructure and data storage: Optical and radio astronomy infrastructure includes both domestic infrastructure and participation in international projects such as the Square Kilometre Array and the European Southern Observatory. It also includes large-scale data storage.*[89]

Further, the Australian Government's broader priorities remain relevant. This includes priorities to increase research-industry collaboration, increase STEM education and skills, and develop advanced technology capabilities. These priorities also highlight the importance of complementarity between optical (i.e., ESO and AAT) and radio (i.e., SKA precursors) astronomy, in terms of education, infrastructure and broader benefits. This complementarity suggests that there is additional potential value that could be gained by taking a portfolio-based approach to Australian astronomy.

Further, the Decadal Plan was developed by the Australian Academy of Science and reflects the astronomy sector priorities. The Decadal Plan includes access to a 30-metre class optical/infrared ELT as a priority. This would be attained if Australia acceded to the ESO Convention. Although the Decadal Plan concludes in 2025, the 2019-20 mid-term review of the Decadal Plan[90] identified recommendations to build on success and make use of new opportunities. These included:

- Achieve full membership of ESO at the earliest opportunity, and well before the current strategic partnership ends in 2027.
- Continue supporting world-class national instrument development capabilities that maximise Australia's engagement, influence and return from global projects.
- Continue investment in training people with strong scientific and translatable skills.
- Explore mechanisms to build stronger ties between the Australian astronomy community, the wider Australian space science community, and the Australian Space Agency.

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[86] Department of Industry, Science and Resources (2023). *Australia's draft National Science and Research Priorities*. Accessed January 2024: https://consult.industry.gov.au/sciencepriorities2.

[87] Ibid.

[88] Department of Industry, Science and Resources (2023). *Revitalising Australia's vision for science and research*. Accessed January 2024: https://www.industry.gov.au/science-technology-and-innovation/revitalising-australias-vision-science-and-research#:~:text=Refreshing%20our%20priorities%20and%20statement,environmental%20benefits%20for%20all%20Australians.

[89] Australian Government (2021). *2021 National Research Infrastructure Roadmap*. Canberra: Australian Government.

[90] Australian Academy of Science (2020). Op. cit.

Would an extension of the current arrangements for the AAT beyond 30 June 2025 result in a continued delivery of current AAT outcomes?

5.2 Potential impact of extending AAT

Key Finding 11 Impact of extending AAT

The AAT is a well-built, high-quality facility that is oversubscribed and delivers valuable scientific output.

However, it is ageing, and no longer considered world-class. An extension to the current arrangements for AAT beyond 30 June 2025 would likely result in gradually diminishing scientific outcomes, and as such, there needs to be some longer-term clarity in the intentions for the AAT.

Some interviewees reported that the AAT competes well with comparable international facilities in terms of research impact and publication metrics because it is a well-built, high-quality facility. It remains oversubscribed and delivers valuable scientific output, despite less funding for maintenance (see section 3.1.3). It is effective in observing across time, enabling large surveys and follow up on data gained from other facilities, and in filling the gap between what telescopes in South Africa and Chile can observe. Two leading edge instruments were commissioned in the last year (Hector and Veloce), which will be useful for surveys over the next 5 years.

However, all interviewees acknowledged that the AAT was ageing, and no longer considered world-class. It was not considered a suitable substitute for the telescopes accessed through the ESO-SP.

Other than Hector and Veloce, there are no new significant instruments under development for AAT. Some interviewees reported that AAT is very expensive to maintain and will become less viable to operate in the next 5-10 years. It does not provide the competitive research edge Australia needs if it is to stay at the forefront in the field of astronomy. Advances to ESO and other telescopes will further diminish the competitiveness of AAT.

AAT is also poorly positioned at low altitude, in a region with high humidity and clouds. Some interviewees suggested that there was value in retaining the AAT site for tourism and educational purposes and retaining the potential to operate smaller telescopes at the site.

Although the current arrangements for AAT could be extended beyond 30 June 2025, the scientific outcomes of the ageing infrastructure are likely to gradually decline over the next 5-10 years. Planning and implementation of astronomy research infrastructure is measured in decades. As such, there needs to be some longer-term clarity in the intentions for the AAT.

Conclusions 6

This chapter summarises the key conclusions.

6.1 Conclusions

Overall, AWLAI has created substantial benefit for Australian researchers. It has met a clear need among the Australian optical astronomy community and aligns with the Australian Government's strategic policy objectives.

AWLAI's design positioned Australian astronomers to realise the intended astronomy research outcomes. However, there were limited industry tender opportunities, and this hindered industry outcomes. The Department's oversight and knowledge transfer structures enable appropriate communication and visibility of the astronomy sector in Australia and internationally.

The ESO-SP has achieved its intended outcomes of ensuring access to 8-metre VLT telescopes and maintaining a critical mass of world-leading astronomy and instrumentation expertise in Australia. This has increased Australia's access to ESO facilities, its international competitiveness, collaboration, scientific output, and workforce and training opportunities. AWLAI has also enabled synergies between ESO, AAT and SKA.

Australia's return on investment in ESO is neutral, with $1 of contributions generating approximately $0.97 in value for Australia from VLT observation time, scientific output, and industrial returns in the form of ESO orders.

The ESO-SP has enabled access to and award of commercial tenders (valued at $9.3 million), industry collaborations, and the commercialisation of astronomy technical expertise. This is despite the restrictions on industry opportunities available through the ESO-SP.

AWLAI has also supported a range of Australian Government broader strategic priorities by delivering broader benefits to other sectors. This includes the movement of skilled personnel and technology from astronomy to other high-value industries.

These benefits would not have been delivered without Australian Government intervention (given the scale of the investment) and access to ESO facilities (given the lack of viable alternatives).

Acceding to the ESO Convention would provide long term stability for the astronomy community, increased access to world-class facilities and enhanced contracting opportunities. This would help maintain Australia's research excellence and align with Government's broader policy objectives.

The ESO-SP is time limited. If Australia decides to pursue accession, the benefits would likely increase due to increased access to facilities and tendering opportunities. Bringing the accession date forward would bring forward these impacts. In contrast, if Australia did not accede, it would forgo the potential benefits of both full membership and, beyond 2027, the ESO-SP. Australian astronomers would lose direct access to ESO facilities and industry would no longer have access to tender opportunities. This would likely reduce Australia's astronomy capabilities and outcomes.

The transition of AAO to the AAT Consortium and Astralis was largely positive, and AAT has continued to deliver valuable scientific output. However, it is no longer world-class, and its utility is likely to decline over time.

6.2 Final thoughts

ACIL Allen's final thoughts on the results of the evaluation are as follows:

1. Accession would bring enhanced access to facilities, industry contracts and decision-making. This would likely result in significant benefit to the Australian astronomy community, with spillover benefits to industry and the broader public.
   a) Accession negotiations would likely be lengthy, and sufficient time needs to be allowed to ensure they are completed in line with the ESO-SP concluding in January 2028.
   b) If Australia does not accede to the ESO Convention, then the astronomy sector needs to be provided with advanced warning (e.g. 2-3 years to account for time taken to apply for and be awarded time for large observing programs) to ensure alternate arrangements can be made. This may include securing access to other facilities, partnering with ESO Members to access ESO facilities, or winding down research operations.
2. The AAT has delivered large scientific value. However, the facility is ageing and unlikely to represent value for money to continue to operate into the medium term. There is a need for forward planning to provide clarity regarding the longer-term intentions for the AAT.
3. There are opportunities to better leverage synergies between optical (i.e. ESO and AAT) and radio (i.e. SKA) astronomy. A portfolio approach to Australian astronomy is needed to ensure these synergies are better captured.
4. Astronomy decision making and funding need to be long term – astronomy is a field that plans in decades, not years. The impacts and efficiency of the domestic astronomy sector (i.e. the operations of the AAT and Astralis) have been, and will likely continue to be, reduced by short term decision making and funding. Greater clarity and certainty around Australia's involvement in ESO would enable better planning across the sector.
5. Outcome data collection and outcome measurement are not funded by the Department, and as such, measurement is undertaken by different organisations (AAL, ESO) and is not coordinated. Interviewees have poor visibility of the usefulness of the data. The Department could guide this process to ensure collection of data of interest and use to the Department.

Appendices

A Terms of reference

A.1 Terms of reference

ACIL Allen's scope of work is to:

— assess the appropriateness, efficiency, effectiveness, and impact, and outcomes of AWLAI

— examine the short-, medium- and long-term impacts of the program

— assess the extent to which the outcomes and goals of the program are being, or are likely to be, delivered (including the key program goal of maintaining Australia's capacity and reputation for conducting world-leading astronomy research)

— examine the impacts of the changes in the management of the AAT and assess to what extent the ESO-SP has provided for new opportunities for Australian businesses to develop and sell their technology to overseas buyers.

The KEQs guiding the evaluation are presented in Table A.1.

Table A.1 Evaluation questions

Design: 1. How appropriate was the design of the program?	
a) What was the need for the program and how well did it (and does it continue to) align with the Australian Government's strategic policy objectives?	i) Was the ESO-SP consistent with the Australian Government's strategic policy objectives? ii) What Strategic priorities and goals (if any) was the Australia-ESO-SP required to address? iii) How well did the design of AWLAI enable the desired project outcomes? What could be done differently or improved? iv) Was Commonwealth intervention necessary to achieve the intended objectives of the program to secure continued Australian astronomy research excellence? v) Did the ESO-SP address the objective to maintain Australia's optical Astronomy capabilities, and access to Astronomy infrastructure as identified by expert stakeholders in the Decadal Plan for Australian astronomy (2016-2025) (the Decadal plan)? vi) What (if any) alternative approach could have been used to maintain Australia's astronomical excellence?
Efficiency: 2. How well was the program administered and delivered?	
a) Was the program administered and delivered as planned? If not, how did it vary?	i) Has the ESO-SP performed as expected? ii) What have been the effects of discontinuing Commonwealth operations of the Australian Astronomical Observatory?

b)	What worked well? What didn't work well or could have been improved or done differently?	i) Were ESO-related opportunities sufficiently translated into scientific, career and financial benefits for the Australian astronomy community? ii) Was research sector access to the AAT affected during the process to transfer to the AAT Consortium? iii) Was Australia's instrumentation capability affected during the process to transfer the Australian Astronomical Optics facilities to the Astralis Consortium? iv) How effective has DISR been in establishing national capabilities in Astronomy, and ensuring Australian businesses are competitive in ESO tenders and global astronomy instrumentation and technology? v) To what extent has the Industry Liaison Officer (ILO) assisted Australian Astronomy Institutions and relevant businesses to be competitive in ESO tenders and global astronomy instrumentation and technology?
c)	Has the cost of the program to date been justified by the benefits and opportunities it generates?	i) Do whole-of-Government priorities continue to justify the Commonwealth involvement in ESO
Outcomes: 3. Is the program working?		
a)	What evidence is there that the program is achieving its intended objectives and outcomes? How do these outcomes compare to the results expected if the government had not intervened?	i) To what extent has the ESO-SP achieved its intended outcomes? (i.e. access to 8m VLT telescopes and maintaining a critical mass of world-leading astronomy and instrumentation expertise in Australia?) ii) Would the research output, impact, and productivity of the Australian Astronomy community be reduced without access to ESO Facilities? If so, do alternate approaches exist to ensure no loss of output, impact, and productivity? iii) Has the ESO-SP improved Australia's production of astronomical instruments and technology and/or Australian Astronomers' international competitiveness and collaboration capacity? iv) To what extent has the ESO-SP generated industry opportunities through access to and award of commercial tenders, industry collaborations, access to global markets, and the commercialisation of astronomy technical expertise in other sectors? v) Has access to the AAT increased, decreased, or remained the same for domestic astronomers? vi) Has the quality and impact of AAT research increased, decreased, or remained the same? vii) Has Australia's optical astronomy instrumentation capability and commercialisation of astronomy-derived practices, services and technology increased, decreased, or remained the same?
b)	What factors (internal and external) are helping and hindering the achievement of intended outcomes, or are likely to do so?	i) Would Australian benefits from the ESO-SP be likely to be increased, reduced, or unaffected by accession to the ESO Convention prior to the end of the ESO-SP? ii) Are there any risks to failing to accede to the ESO Convention in a timely fashion? (i.e. if there is a gap between the end of the ESO-SP and accession as full members)
c)	What, if any, unintended consequences have there been, positive and negative, and for whom?	i) How has the current global financial situation and COVID pandemic affected the business case for ESO Membership?
d)	To what extent has the program contributed to, or enabled the outcomes it was designed to achieve?	i) Would an extension of the current arrangements for the AAT beyond 30 June 2025 result in a continued delivery of current AAT outcomes? ii) Would an extension of the current ESO-SP beyond 2027, rather than accession to full membership, result in continued delivery of current astronomy outcomes?

Lessons learned: 4. What lessons have been learned?
a) What, if any, lessons can be drawn from AWLAI, and particularly the ESO-SP, to influence future astronomy policy and improve the efficiency and efficacy of similar programs going forward?

Source: AWLAI Program Impact Evaluation – Statement of Requirements

Stakeholder engagement B

B.1 Interview discussion guide

Background

1. Please describe the origins of AWLAI and your role / involvement in it.

Design: *(How appropriate was the design of the program?)*

2. Do you believe there was need for the program? Why?
3. Does AWLAI align with the Government's strategic policy objectives? Please explain why you believe this.
4. Could alternative approaches been explored to maintain Australia's astronomical excellence? If so, what?
5. What strategic priorities and goals was the Australia ESO Strategic Partnership (ESO-SP) required to address?
   a) Have these priorities/goals changed since the program's inception? Have new priorities/goals been introduced over time?
   b) Do the Government's priorities continue to justify Australian involvement in ESO?
6. What data collection and outcome measurement processes have been built into the design of AWLAI?
7. What would have happened in the absence of AWLAI?

Efficiency: *(How well was the program administered and delivered?)*

8. Have there been any challenges with administering AWLAI? If so, what were they, and what was done to address these?
9. What could have been improved or done differently?
10. What do you believe has worked well in the delivery of AWLAI?
11. What has been the impact of separating the Australian Astronomical Observatory (AAO) into the Anglo Australian Telescope (AAT) Consortium and an astronomy instrumentation consortium (Astralis)?
12. Was the research sector's access to the AAT affected during the process to transfer to the AAT Consortium? If so, how?

13. Was Australia's instrumentation capability affected during the process to transfer the Australian Astronomical Optics facilities to the Astralis Consortium? If so, how?

14. What have been the effects of transferring the responsibility for the operational control of the Australian Astronomical Observatory from the Commonwealth government to the research sector, noting that the Commonwealth retains ownership of the AAT building?

15. Australia has appointed an Industry Liaison Officer (ILO) to be the primary contact between ESO and Australian industry. What do you see as the ILO's role(s)?

    a) To what extent has the ILO been successful in fulfilling its role(s)?

16. What are the Government's expectations of AWLAI, and how it contributes to research impact?

    a) In your view, has the ESO-SP performed as expected?
    b) Do whole-of-Government priorities continue to justify Australian involvement in ESO, and/or the continuation of the AAT?

Outcomes and impacts *(Is the program working?)*

17. The following questions seek your views on the extent to which the program is achieving its intended objectives and outcomes.

    a) To what extent has the ESO-SP achieved its intended outcomes (i.e. access to 8m VLT telescopes and maintaining a critical mass of world-leading astronomy and instrumentation expertise in Australia?)

    b) Would the research output, impact, and productivity of the Australian astronomy community be reduced without access to ESO facilities? If so, do alternate approaches exist to ensure no loss of output, impact, and productivity?

    c) Has the ESO-SP improved Australia's production of astronomical instruments and technology and/or Australian astronomers' international competitiveness and collaboration capacity?

    d) To what extent has the ESO-SP generated industry opportunities through access to and award of commercial tenders, industry collaborations, access to global markets, and the commercialisation of astronomy technical expertise in other sectors?

    e) Can you identify examples of spill overs from astronomy research (e.g. instrument development, precision engineering, etc)?

    f) Has access to the AAT increased, decreased, or remained the same for domestic astronomers?

    g) Has the quality and impact of AAT research increased, decreased, or remained the same?

    h) Has Australia's optical astronomy instrumentation capability and commercialisation of astronomy-derived practices, services and technology increased, decreased, or remained the same?

18. Are there examples where researchers working in astronomy have moved on to apply their skills in another research fields or areas of the Australian economy?

19. Has the program resulted in other economic, social and/or environmental impacts that are not included in the answers to the questions above? If so, please describe them.

20. How would the outcomes that have been achieved through astronomy research in Australia have changed in the absence of Government funding?

21. What, if any, factors (internal and external) are helping or hindering the achievement of intended outcomes, or are likely to do so?
22. Would accession to the ESO Convention affect AWLAI? If so, how?
23. What, if any, benefits from the ESO-SP would change by accession to the ESO Convention?
24. Are there any risks to failing to accede to the ESO Convention by any particular time? If so, what are they?
25. Would an extension of the current ESO-SP beyond 2027, rather than accession to full membership, result in changes to current astronomy outcomes? If so, how?
26. Has the AWLAI resulted in any unintended consequences (positive or negative)? What were they and who was affected?
27. Are you aware of any reports that have examined the impacts of astronomy research?

Lessons learned

28. What, if any, lessons can be drawn from AWLAI, and particularly the ESO-SP, to influence future astronomy policy and improve the efficiency and efficacy of similar programs going forward?

Other

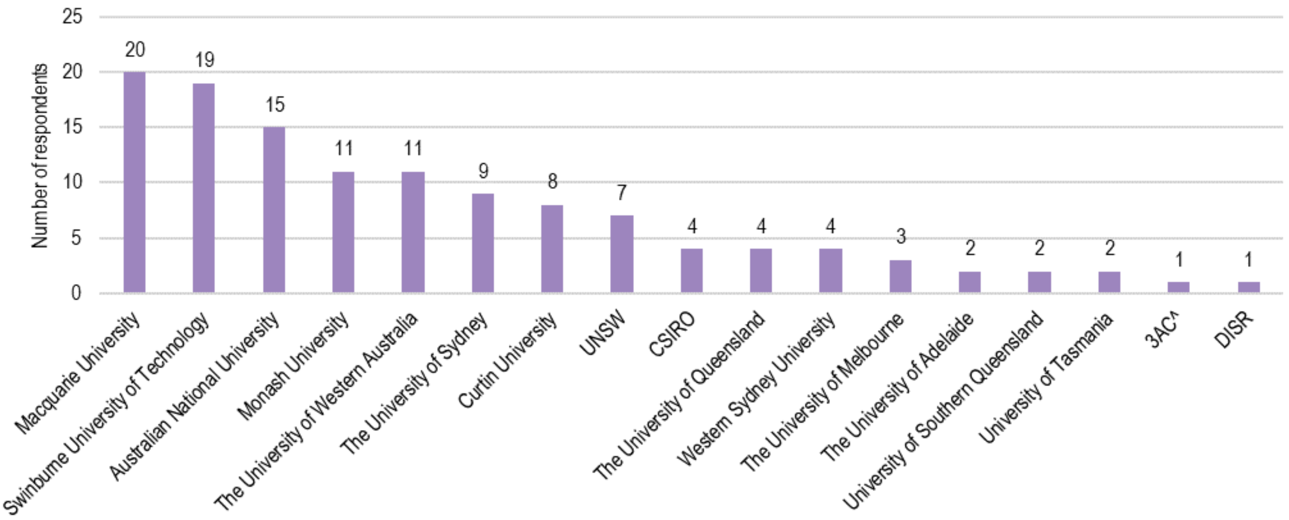
Are there any other comments you would like to make or questions you would like to ask us?

B.2 Evaluation survey

B.2.1 Overview of survey responses and demographics

Figure B.1 shows that most respondents were from universities, with the most respondents recorded from Macquarie University.

Figure B.1 Respondents' institute/organisation?



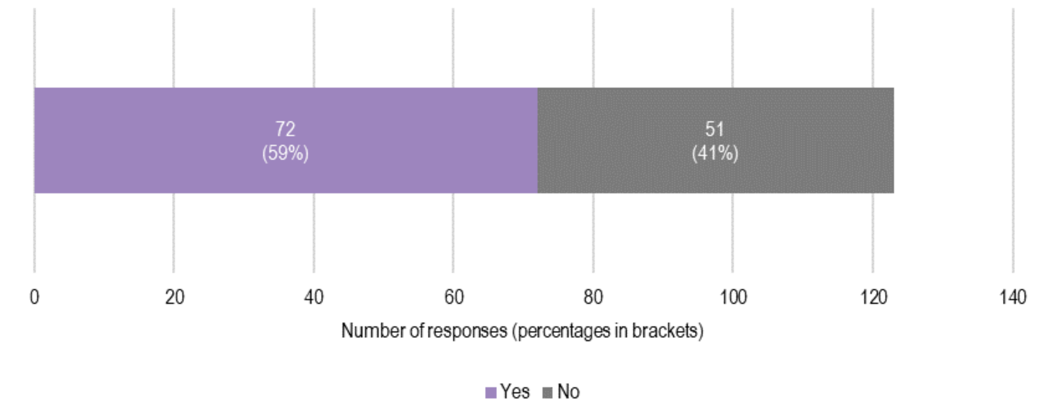
^3AC refers to Australian Association for Astronomy in Culture
n=123
Source: ACIL Allen 2023 Survey of the astronomy sector

B.2.2 Engagement with ESO facilities

Use of ESO facilities

Figure B.2 shows that most respondents (58%) applied for observation time on an ESO telescope through the ESO-SP.

Figure B.2 Have you applied for observation time, in any role, on any ESO telescope through the ESO-SP?

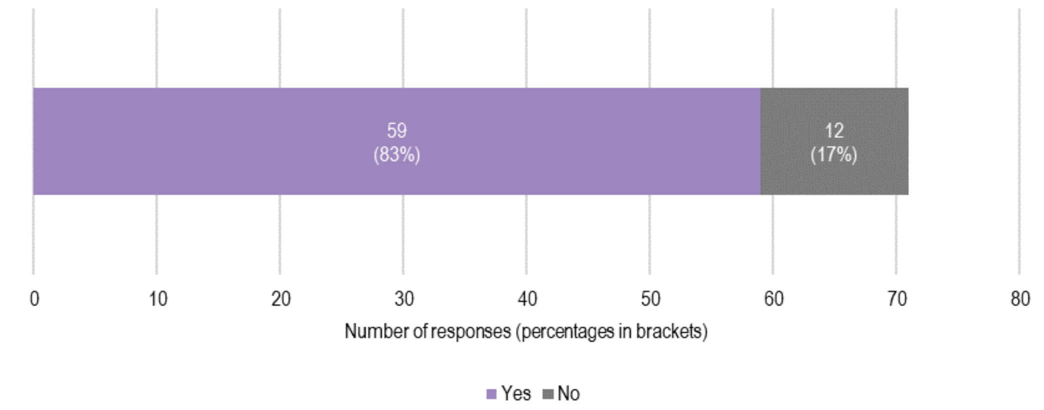


n=123

Source: ACIL Allen 2023 Survey of the astronomy sector

Of those that had applied for ESO observation time, over 80% of respondents received observation time on any ESO telescope through the ESO-SP (see Figure B.3).

Figure B.3 Have you received any observation time, in any role, on any ESO telescope through the ESO-SP?



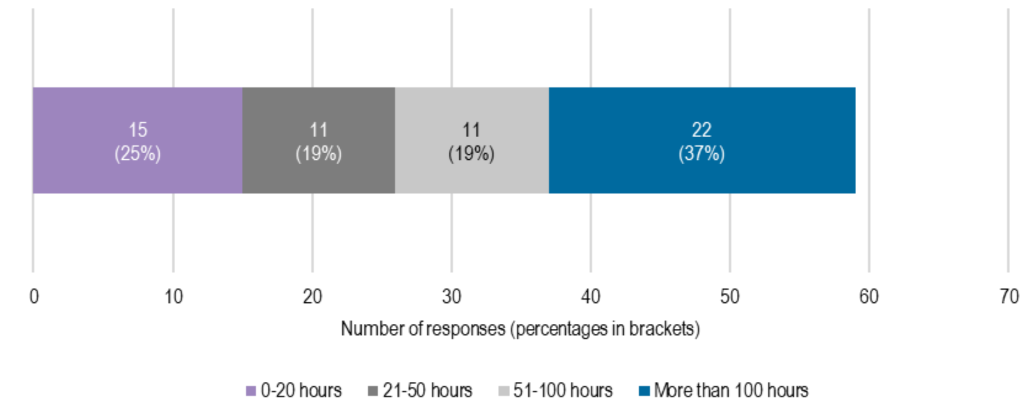
n=71

Source: ACIL Allen 2023 Survey of the astronomy sector

B.2.3 Respondents that received observation time on ESO facilities

Of those that had received observation time on ESO telescope(s), Figure B.4 shows that approximately 37% of all respondents reported having received *more than 100 hours* of observation time on an ESO telescope.

Figure B.4 How many hours of observation time have you received, in any role, on any ESO telescope?

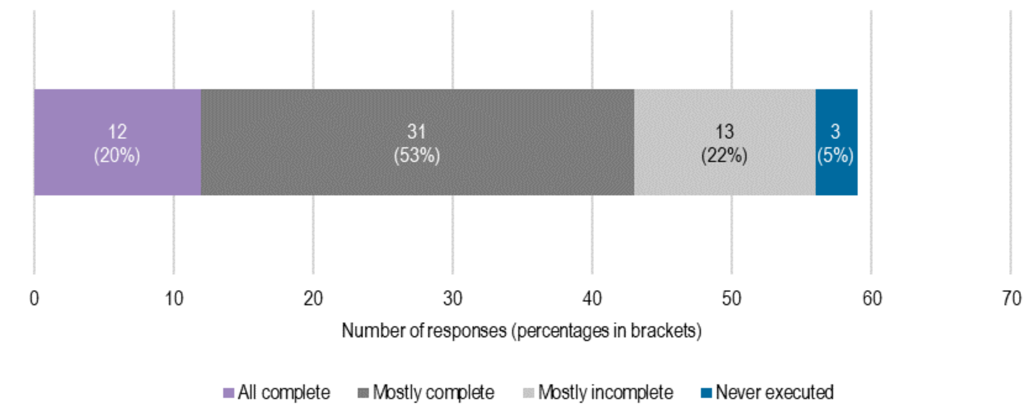


n=59

Source: ACIL Allen 2023 Survey of the astronomy sector

Of those that had received observation time on ESO telescope(s), more than 70% of respondents reported that their programs under observation time allocations were *mostly complete* or *all complete* (see Figure B.5).

Figure B.5 Over all of your observation time allocations, are these programs:

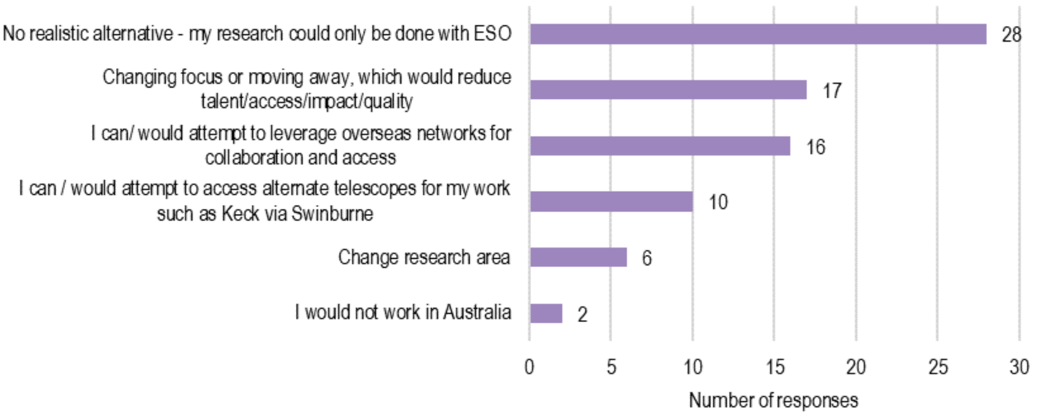


n=59

Source: ACIL Allen 2023 Survey of the astronomy sector

Qualitative analysis of free text responses shows that across respondents addressing this question, most reported that there was no suitable alternative to ESO's facilities (see Figure B.6).

Figure B.6 What other approaches or programs would you use if you did not have access to ESO Facilities and what would be the impact of this?



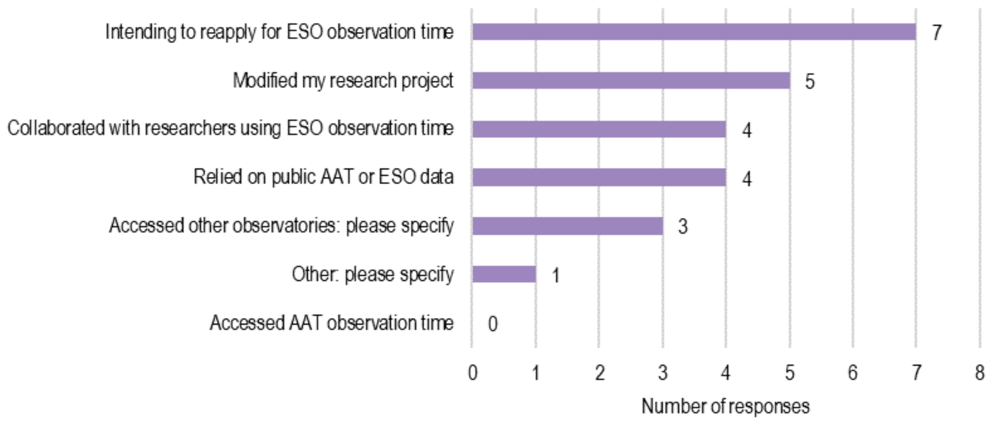
n=46

Source: ACIL Allen 2023 Survey of the astronomy sector

Respondents that did not receive observation time on ESO facilities

For those that did not receive any observation time on ESO facilities (as in Figure B.3), most respondents (58%) reported that they were intending to reapply for ESO observation time (see Figure B.7).

Figure B.7 Which of the following approaches, if any, have you used or do you intend to use to replace access to ESO?



'Accessed other observatories: Please specify' respondents did not input any text. The single response that selected 'Other: please specify' stated they 'applied and received Keck time through Swinburne'.

n=12

Source: ACIL Allen 2023 Survey of the astronomy sector

Of researchers that did not secure access to ESO facilities, Figure B.8 shows that most respondents (42%) reported that their research was delayed as a consequence.

Figure B.8 How did this impact your research?

n=7

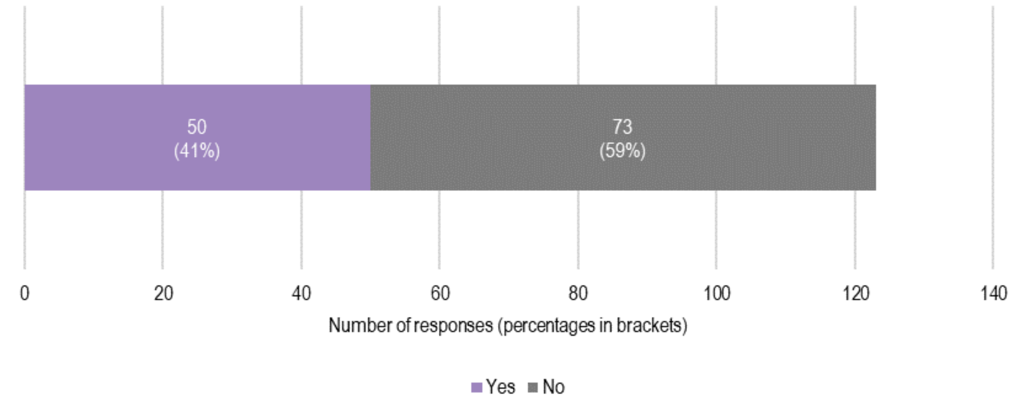
Source: ACIL Allen 2023 Survey of the astronomy sector

B.2.4 AAT

Use of AAT facilities

Figure B.9 shows that approximately 41% of respondents have applied for observation time with AAT.

Figure B.9 Have you applied for observation time on the Anglo Australian Telescope (AAT)?



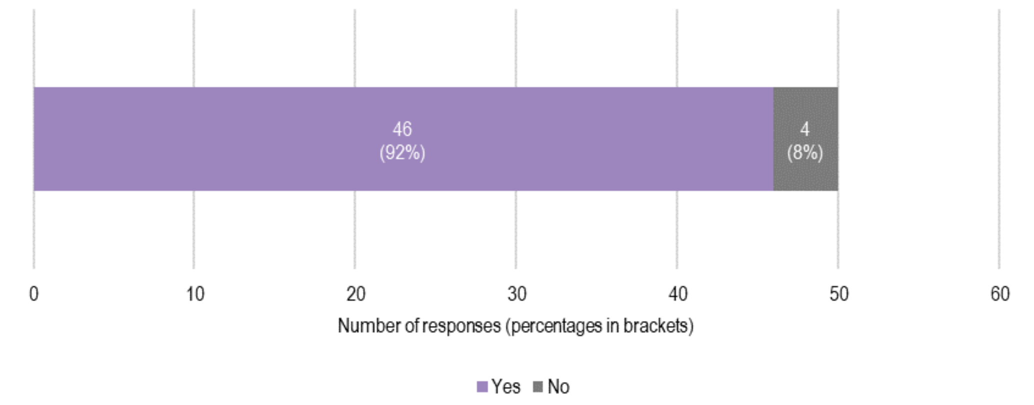
n=123

Source: ACIL Allen 2023 Survey of the astronomy sector

Respondents that received observation time on AAT

Of those that applied for observation time on AAT, Figure B.10 shows that approximately 92% of respondents were successful in securing observation time.

Figure B.10 Have you received any observation time on AAT?

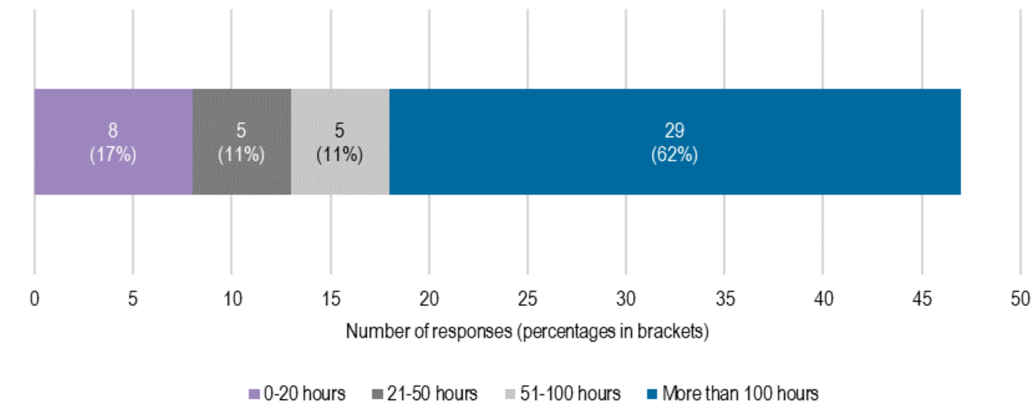


n=50

Source: ACIL Allen 2023 Survey of the astronomy sector

Figure B.11 shows that out of those that had received time on AAT, most respondents (62%) received *more than 100 hours* of observation time on AAT.

Figure B.11 How many hours of observation time have you received, in any role, on AAT?

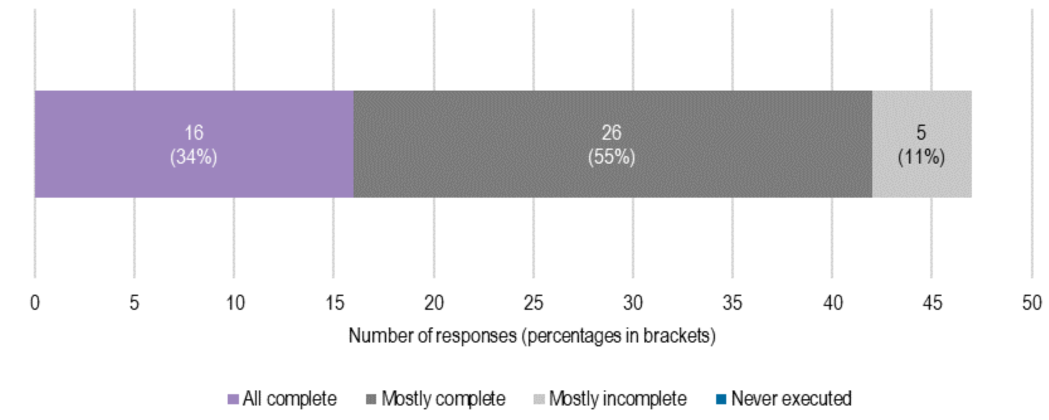


n=47

Source: ACIL Allen 2023 Survey of the astronomy sector

Figure B.12 shows that of those who have received time on AAT, respondents' programs were *mostly complete* (55%) or *all complete* (34%).

Figure B.12 Over all of your observation time allocations, are these programs:

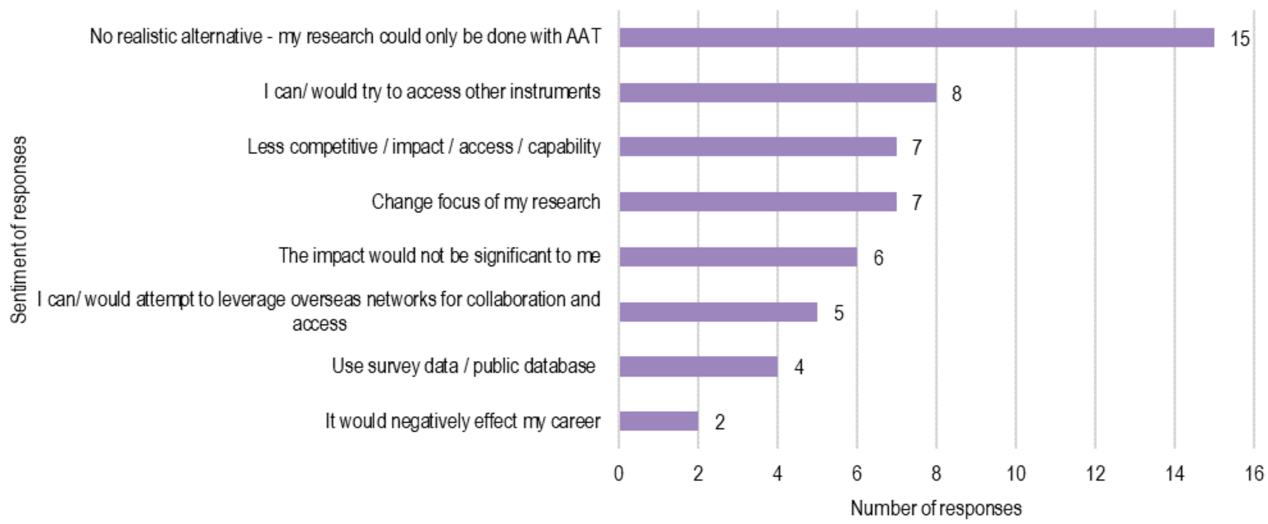


n=47

Source: ACIL Allen 2023 Survey of the astronomy sector

Qualitative analysis of free text responses shows that across respondents addressing this question, most reported that there was no suitable alternative to AAT (see Figure B.13).

Figure B.13 What other approaches or programs would you use if you did not have access to AAT and what would be the impact of this?



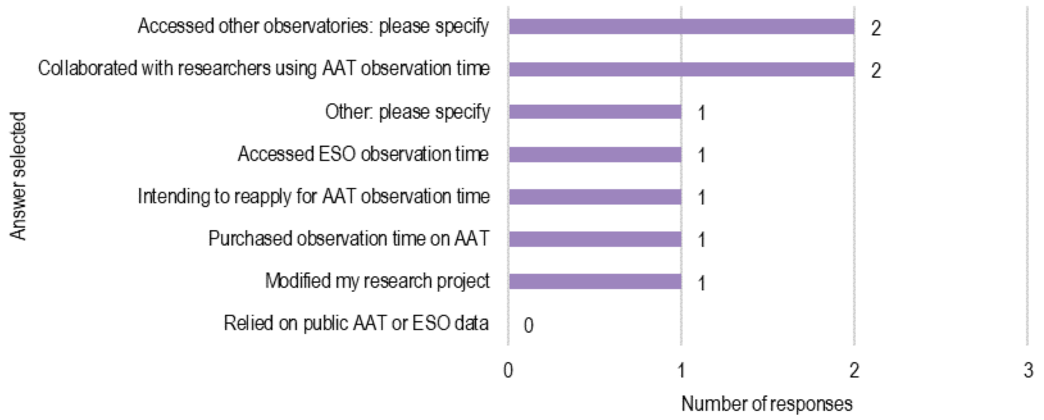
n=37

Source: ACIL Allen 2023 Survey of the astronomy sector

Respondents that did not receive observation time on AAT

Figure B.14 recorded 4 responses from those that had applied for but not received AAT time. The most common being that they have used / would use other observatories (2 responses) or would collaborate with researchers using AAT observation time (2 responses).

Figure B.14 Which of the following approaches, if any, have you used or do you intend to use to replace access to AAT?



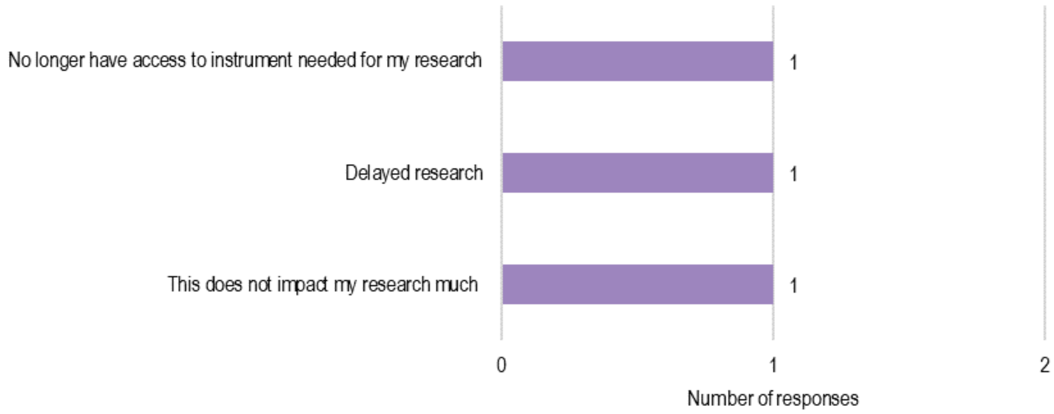
'Accessed other observatories: please specify' responses specified ESO (MUSE) and the Wendelstein telescope. 'Other: please specify' responded that their research was transferred to ESO 4MOST.

n=4

Source: ACIL Allen 2023 Survey of the astronomy sector

Figure B.15 displays 3 free text responses from those that had applied for access to AAT, regarding the impact of losing AAT facilities.

Figure B.15 How did this impact your research?



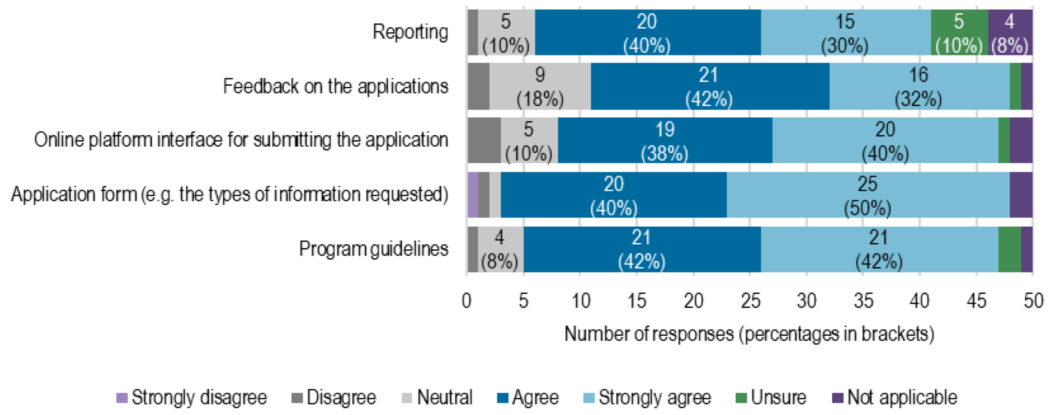
n=3

Source: ACIL Allen 2023 Survey of the astronomy sector

Accessing AAT facilities

Figure B.16 shows that of respondents who had applied for access to AAT, most either *agree* or *strongly agree* that the processes for accessing AAT facilities were clear and easy to follow.

Figure B.16 To what extent do you agree that the following processes for accessing AAT facilities were clear/easy to follow:

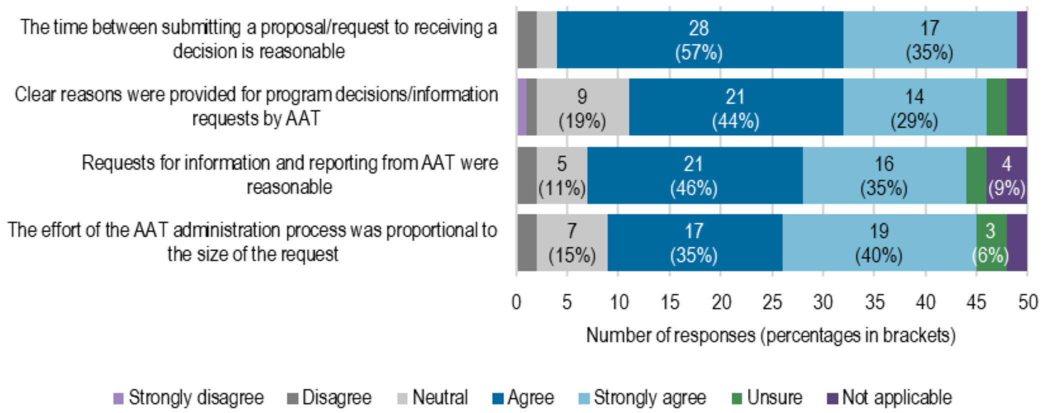


n=50

Source: ACIL Allen 2023 Survey of the astronomy sector

Of respondents who had applied for access to AAT, most *agree* that their experiences with AAT were reasonable, clear and the effort provided by AAT was satisfactory (see Figure B.17).

Figure B.17 Thinking about your experiences with AAT, to what extent do you agree with the following statements

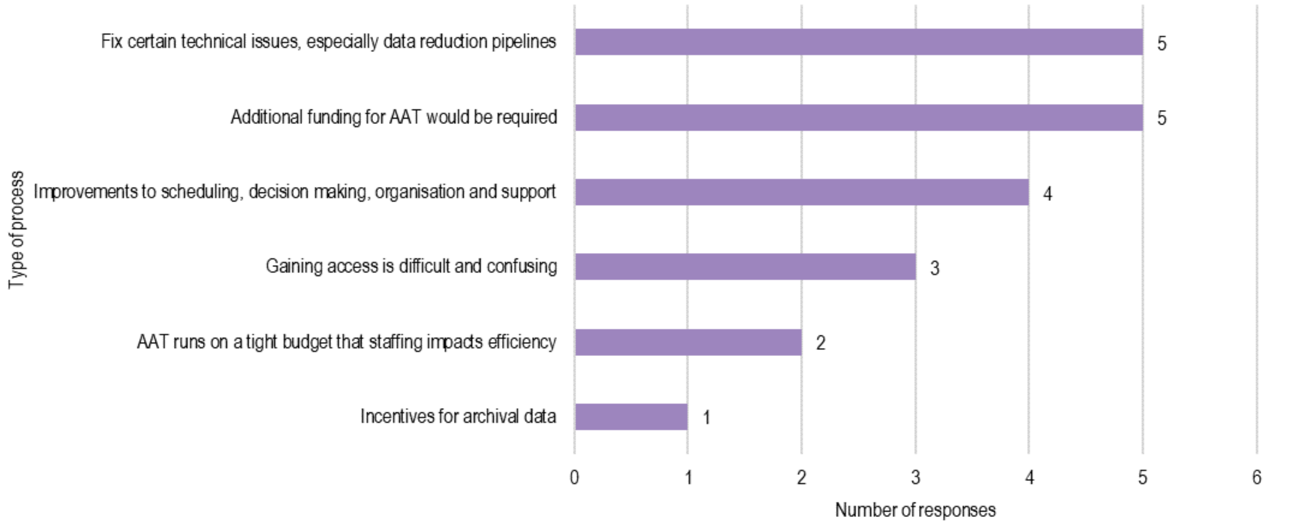


n=50

Source: ACIL Allen 2023 Survey of the astronomy sector

Quantitative analysis applied to free text responses (see Figure B.18) highlights that respondents reported that the funding of AAT and technical issues, particularly data reduction pipelines could be improved. Of the 26 total responses, 6 provided positive feedback or stated that the question did not apply to them.

Figure B.18 How could the AAT processes be improved and how important are these improvements to you?



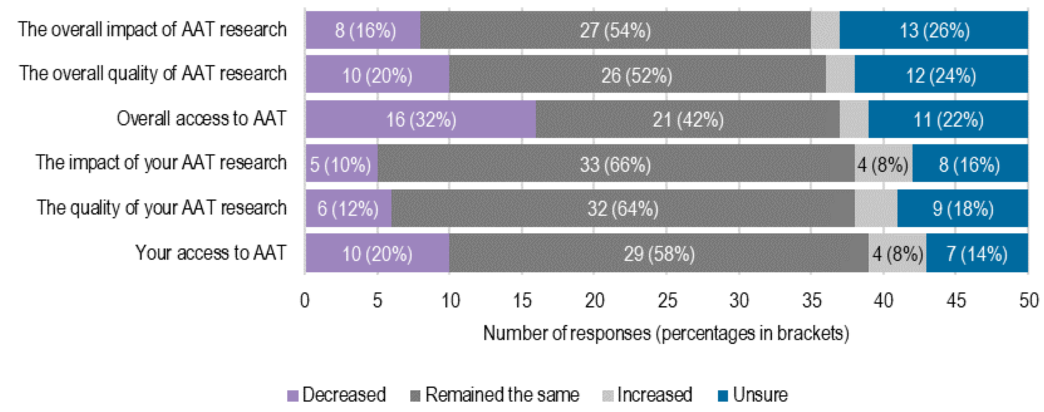
n=26

Source: ACIL Allen 2023 Survey of the astronomy sector

Impact of transferring management of the AAT to the AAT Consortium

Those who had applied for access to AAT provided feedback on the transfer of the AAT to the AAT Consortium. Figure B.19 shows that the transfer did not change the perceived impact, quality, or access of AAT research for most respondents.

Figure B.19 The Australian Government transferred management of the AAT to the AAT Consortium in 2018. To what extent did the following change after this transfer process?



n=50

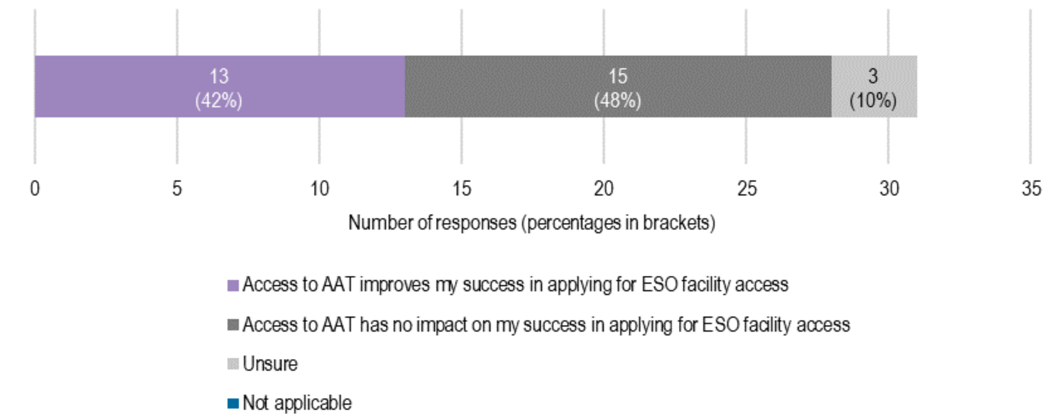
Source: ACIL Allen 2023 Survey of the astronomy sector

B.2.5 Synergies between facilities

Synergies between ESO and AAT facilities

Those who had received time on both ESO and AAT were asked to rate the effect of AAT access on applying to ESO facilities. Figure B.20 shows that 42% of all respondents reported that *access to AAT has improves their success in applying for ESO facility access.*

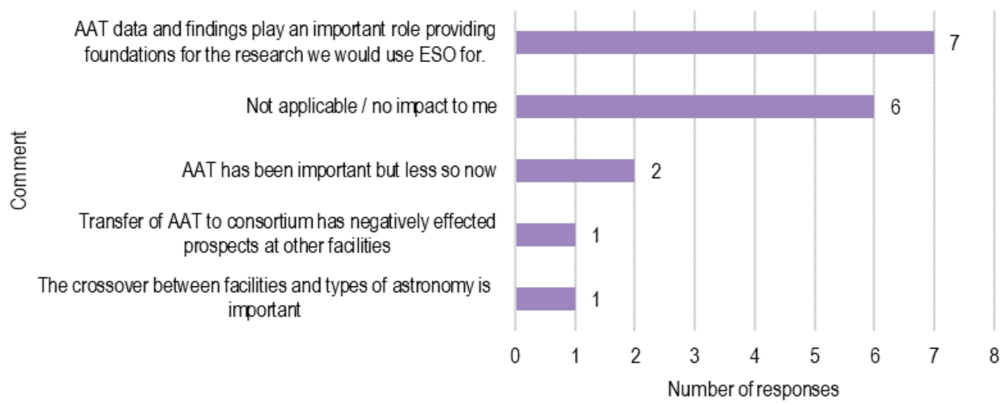
Figure B.20 To what extent does your access to AAT impact the success of your applications to ESO facilities?



n=31
Source: ACIL Allen 2023 Survey of the astronomy sector

Qualitative analysis of free text responses (see Figure B.21) shows that when asked for further comment regarding how access to AAT impacted their success in applying to ESO services, most respondents reported that AAT's data and findings are an important foundation for ESO-based research.

Figure B.21 Please provide any further comments

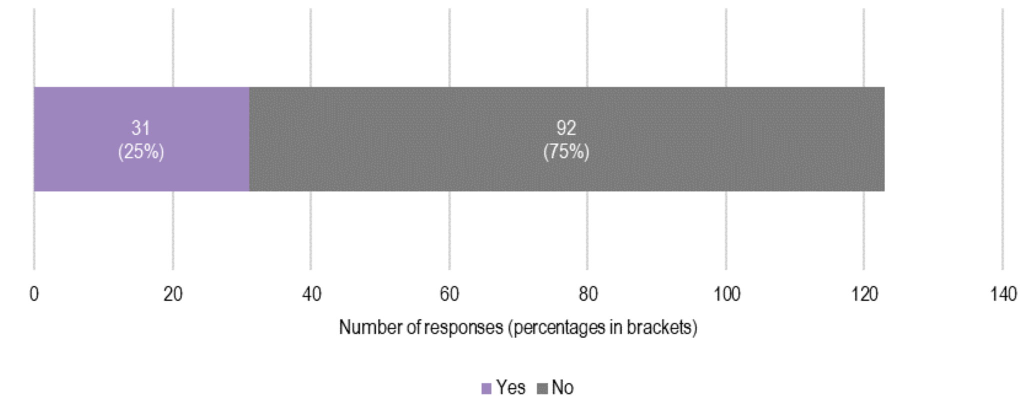


n=17
Source: ACIL Allen 2023 Survey of the astronomy sector

Synergies between SKA, and AAT or ESO

Figure B.22 shows that across all respondents, most (75%) had not received time on SKA precursor telescopes.

Figure B.22 Have you received time on the Square Kilometre Array (SKA) precursor telescopes (ASKAP or Murchison Widefield Array)?

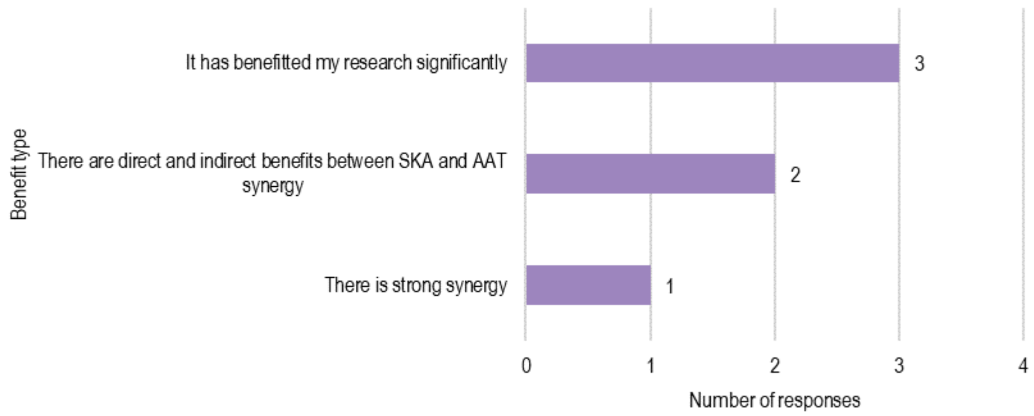


n=123

Source: ACIL Allen 2023 Survey of the astronomy sector

Figure B.23 displays free text responses of the synergies that respondents perceive between AAT and SKA. This question received 6 responses from those who had accessed both AAT and SKA precursor telescope facilities. Responses most frequently highlighted that the synergy has benefitted their research significantly.

Figure B.23 To what extent have there been any synergies or additional benefit from accessing both the AAT and SKA precursor telescopes facilities?

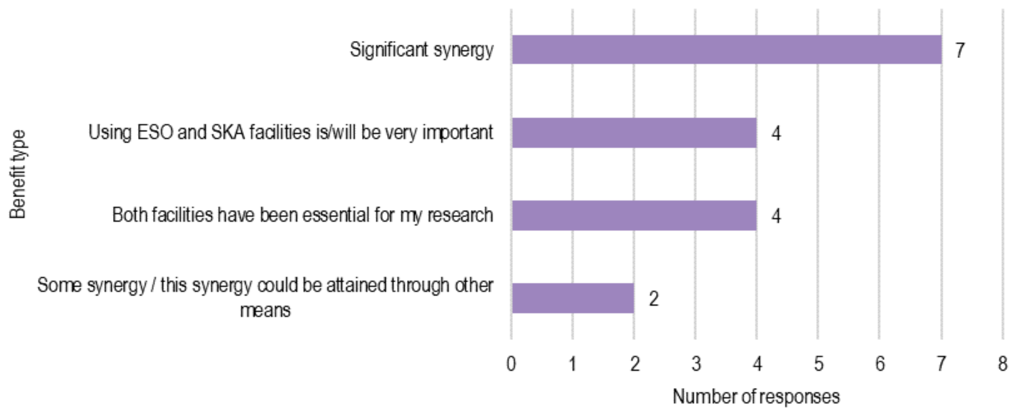


n=6

Source: ACIL Allen 2023 Survey of the astronomy sector

Qualitative analysis of free text responses (see Figure B.24) shows that most respondents who had accessed both ESO and SKA precursor telescope facilities (41%) reported that there has been *significant synergy* gained from accessing both the ESO and SKA precursor telescope facilities.

Figure B.24 To what extent have there been any synergies or additional benefit from accessing both the ESO and SKA precursor telescopes facilities?

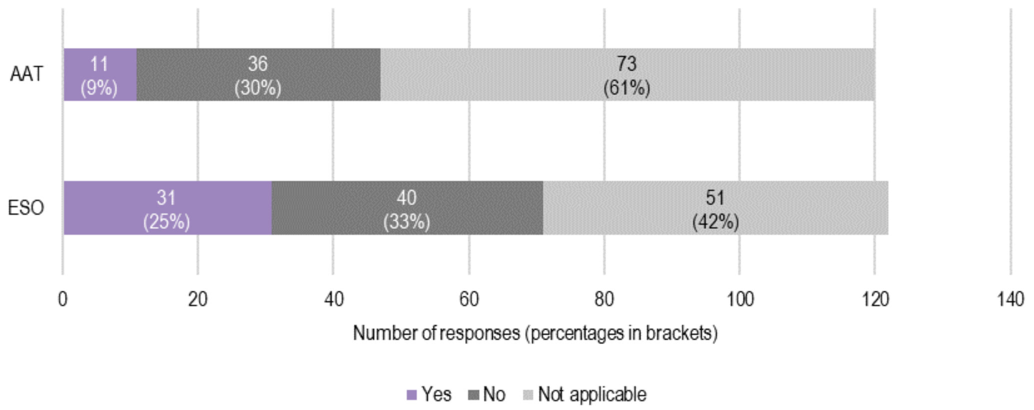


n=17
Source: ACIL Allen 2023 Survey of the astronomy sector

B.2.6 Perspectives on AAL support

Figure B.25 shows that most respondents had not received support from AAL to access time on the AAT (77% of responses excluding those who selected not applicable) or ESO (56% of responses excluding those who selected not applicable) facilities.

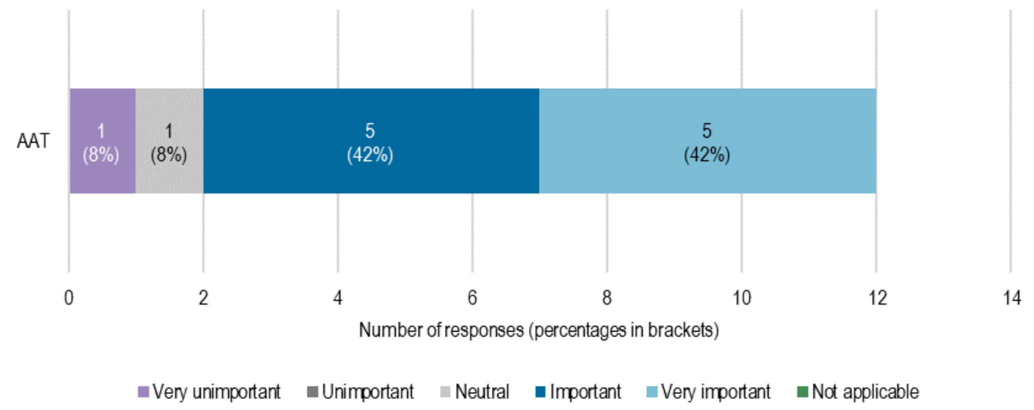
Figure B.25 Did AAL support you to access time on the following facilities?



n=120 for AAT
n=122 for ESO
Source: ACIL Allen 2023 Survey of the astronomy sector

Figure B.26 collected responses from those that reported AAL supported them to access time on AAT. Of those, 84% of respondents said that AAL's support was either *important* (42%) or *very important* (42%).

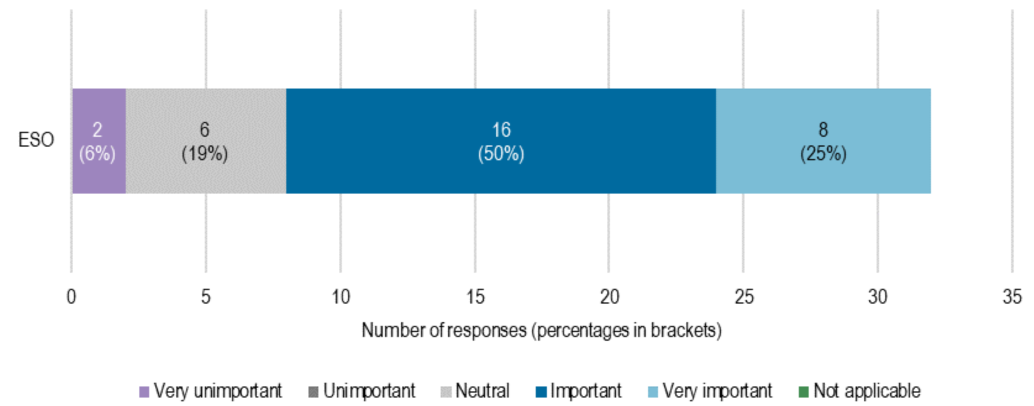
Figure B.26 How important was that support to you (AAT)?



n=12
Source: ACIL Allen 2023 Survey of the astronomy sector

Figure B.27 collected responses from those that reported AAL supported them to access time on ESO. Of those, 75% of respondents said that AAL's support was either *important* (50%) or *very important* (25%).

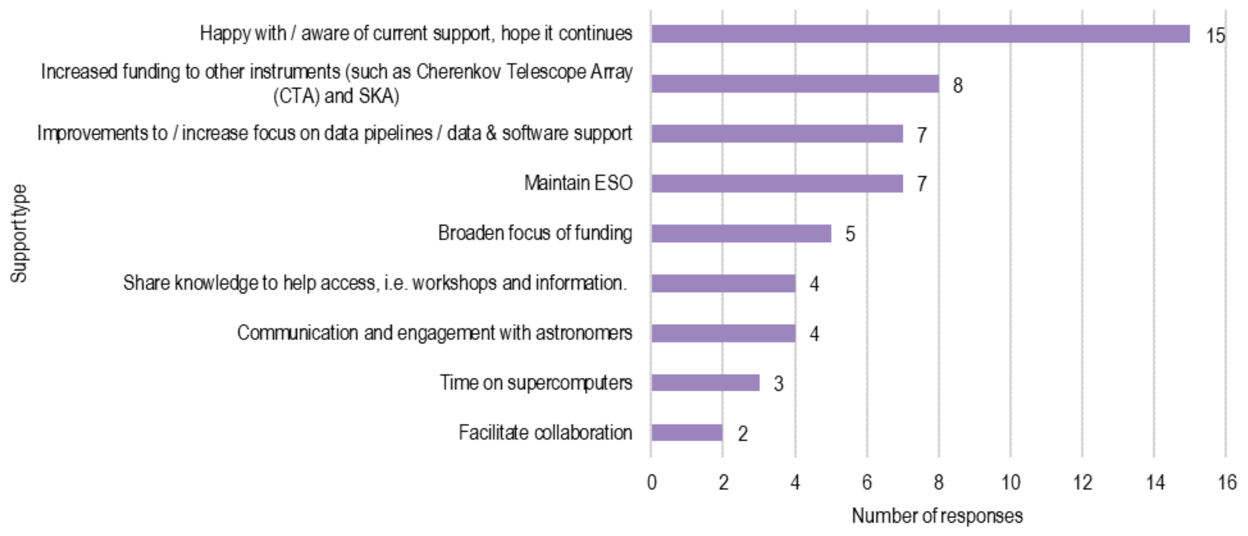
Figure B.27 How important was that support to you (ESO)?



n=32
Source: ACIL Allen 2023 Survey of the astronomy sector

Figure B.28 highlights that the most common answer was that they are happy with the current level of support and hopes that it will continue. Of the 49 responses, 4 relayed that the question was not relevant to them or had no specific feedback. The following themes were only expressed by one respondent: *Less focus on ESO, AAL is trying to do too much at once, Greater transparency, Provide financial support to researchers between grants.*

Figure B.28 How could AAL better support you in your astronomy research, and how important is this improvement to you?

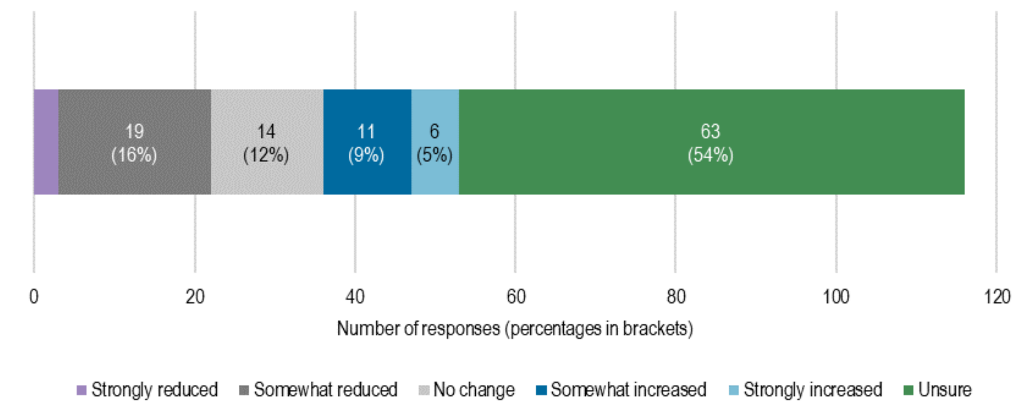


n=49
Source: ACIL Allen 2023 Survey of the astronomy sector

B.2.7 Respondent perspectives on Astralis

Figure B.29 shows that most respondents (54%) reported that they were unsure of whether Australia's instrumentation capability was affected after the management transfer to Astralis.

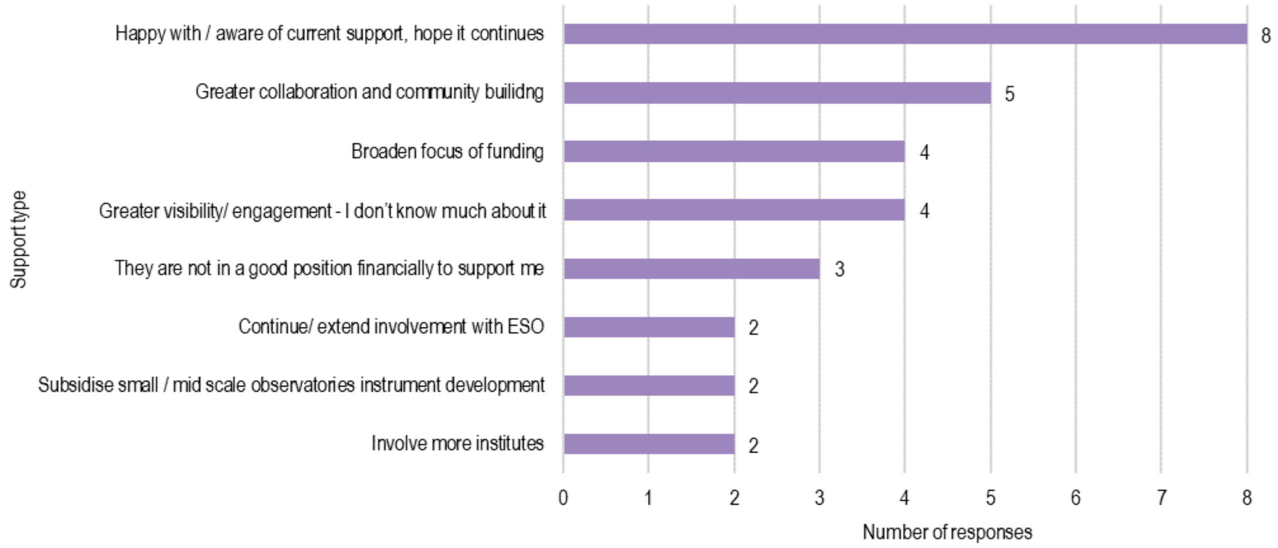
Figure B.29 The Australian Government transferred management of the Australian Astronomical Optics facilities to Astralis in 2018. To what extent was Australia's instrumentation capability affected after the transfer process?



n=116
Source: ACIL Allen 2023 Survey of the astronomy sector

Figure B.30 used qualitative analysis of free text responses to show that most respondents were content with the current support and hope it continues. Of the 46 responses, 9 reported that the question was not applicable or had no specific feedback. The following themes were only expressed by one respondent: *Focus on fewer projects, Greater job security, More support for AAT, Transparency, More consideration of technical and support staff, Focus on reliability, More support to nodes.*

Figure B.30 How could Astralis better support you in your astronomy research, and how important is this improvement to you?

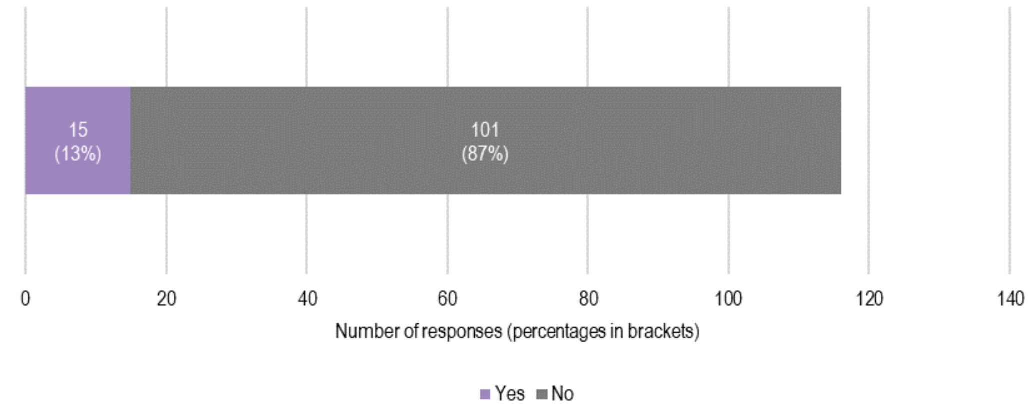


n=46
Source: ACIL Allen 2023 Survey of the astronomy sector

B.2.8 Industry Liaison Officer

Figure B.31 shows that 87% of respondents said that they have not interacted with the Department's ILO in any way.

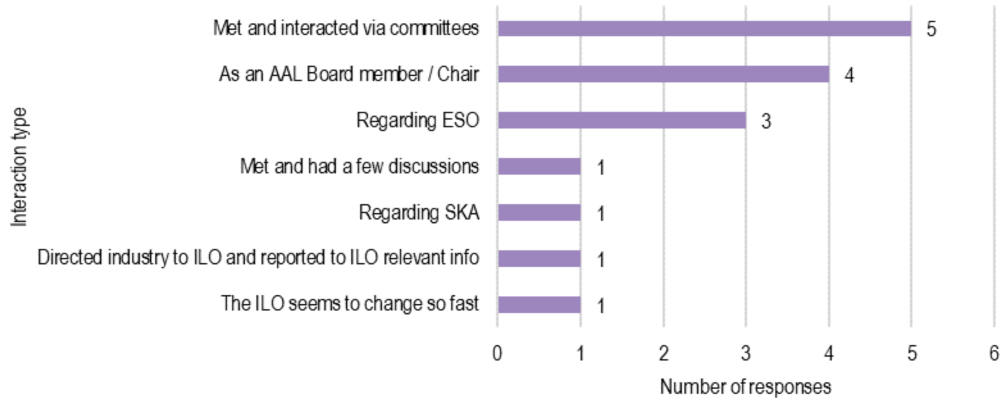
Figure B.31 Have you interacted with the Departmental Industry Liaison Officer (ILO) in any capacity?



n=116
Source: ACIL Allen 2023 Survey of the astronomy sector

Qualitative analysis of free text responses (see Figure B.32) shows that of those who interacted with the ILO, the most frequent response (31%) was that they had *met and interacted via committees*.

Figure B.32 Please describe your interaction with the ILO.

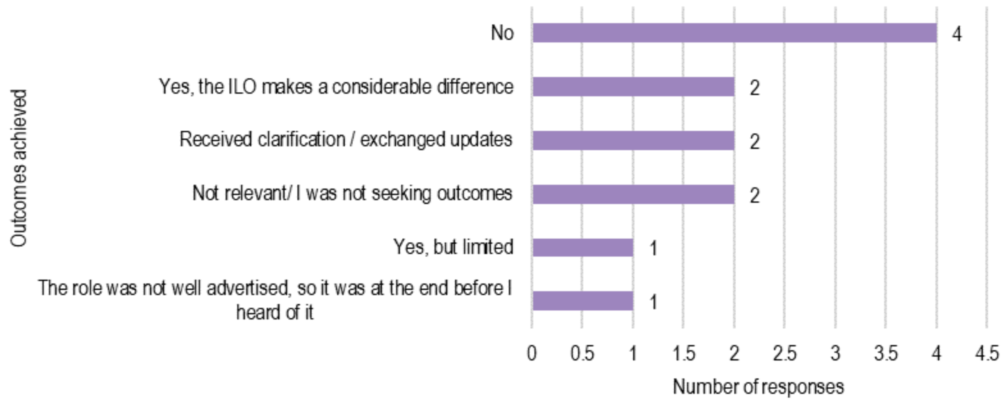


n=16

Source: ACIL Allen 2023 Survey of the astronomy sector

Figure B.33 used qualitative analysis of free text responses to show that respondents most commonly did not achieve any outcomes from their engagement with the ILO.

Figure B.33 Did you achieve any outcomes as a result of your engagement with the ILO?



n=12

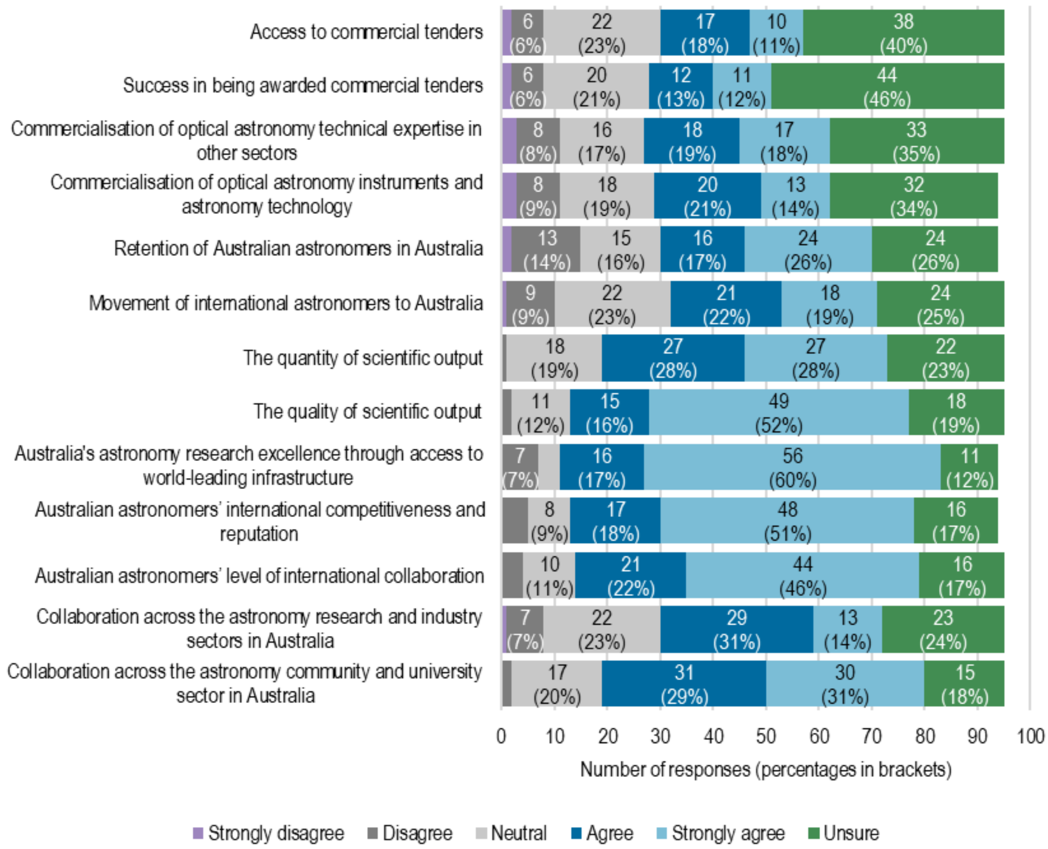
Source: ACIL Allen 2023 Survey of the astronomy sector

B.2.9 Perspectives on AWLAI program outcomes

AWLAI program intended outcomes

Figure B.34 shows that most respondents *strongly agree* that AWLAI program is achieving its intended outcomes. However, many were unsure, particularly around commercial outcomes (e.g. access to and award of tenders).

Figure B.34 To what extent do you agree that AWLAI is achieving its intended outcomes of increasing:

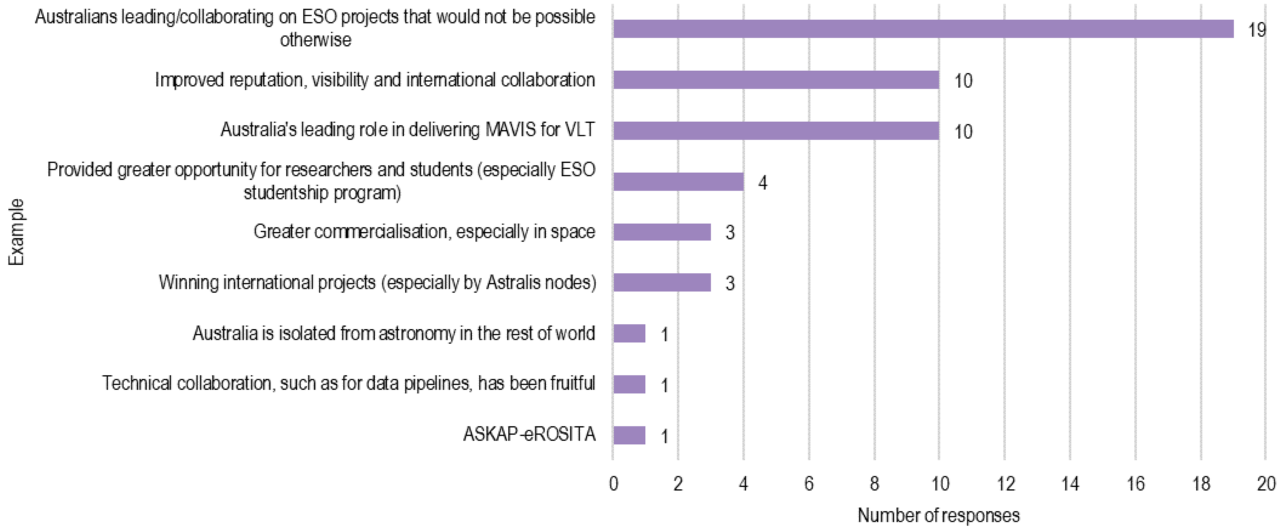


n=95

Source: ACIL Allen 2023 Survey of the astronomy sector

Figure B.35 used qualitative analysis of free text responses. Results show that *Australians leading/collaborating on ESO projects that would not be possible otherwise* is the most commonly reported significant example of AWLAI's impact.

Figure B.35 Please provide the most significant examples (of impacts achieved by AWLAI) you can think of:

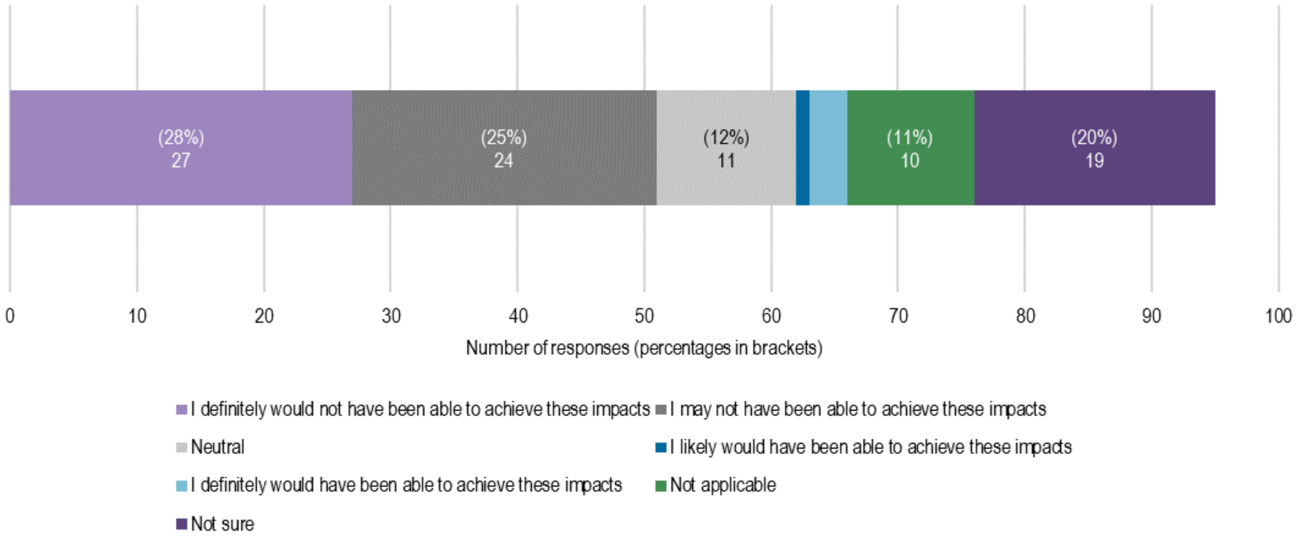


n=54

Source: ACIL Allen 2023 Survey of the astronomy sector

Figure B.36 shows that approximately half of respondents *definitely would not* or *may not have been able to achieve these impacts* without AWLAI.

Figure B.36 Would the outcomes you identified above have been achieved without AWLAI?

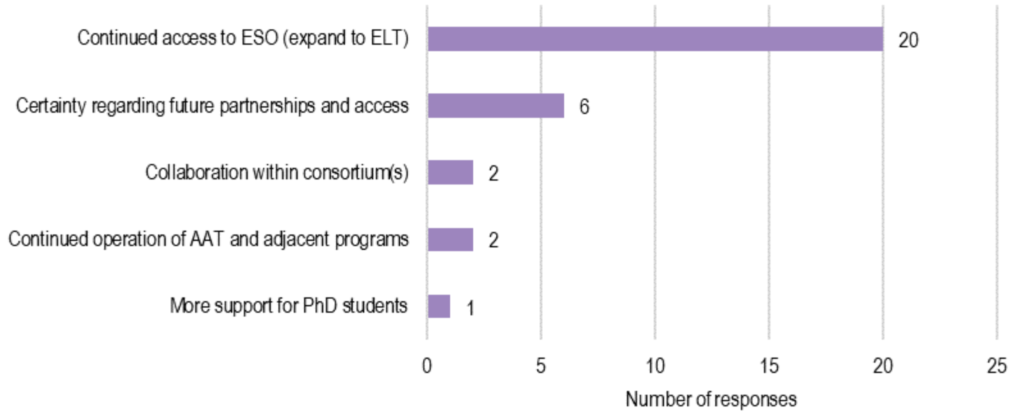


Source: n=95

Source: ACIL Allen 2023 Survey of the astronomy sector

Figure B.37 used qualitative analysis of free text responses. Results show that *continued access to ESO (expand to ELT)* was most commonly identified as contributing to AWLAI program outcomes (50%). Some (2) respondents found the question was not applicable or had no specific suggestions. Some themes were identified by one respondent, including the need for more support for PhD students, training on how to apply for ESO time, the need for long term engagement with SKA, better commercialisation, synergy between space optics and astronomical optics, a more favourable political environment, and the need for continued funding for Astralis.

Figure B.37 Are there any current or future factors that helped or could help achieve these outcomes?

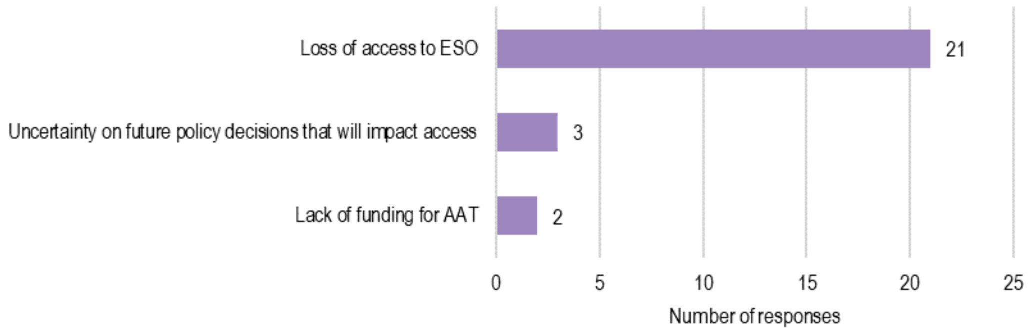


n=40

Source: ACIL Allen 2023 Survey of the astronomy sector

Figure B.38 used qualitative analysis of free text responses. Respondents reported that the *loss of* access to ESO has or is likely to hinder the achievement of AWLAI program outcomes (55%). Some themes were identified by one respondent, delays to building ELT and missed contracting opportunities, lack of funded PhDs, limited government support and investment in high-tech manufacturing, less and less stable funding for AAT and Astralis to capitalise on ESO contract opportunities, difficulties engaging with ESO due to Australia's geographic isolation, the need for a broader focus of astronomy in Australia (including space).

Figure B.38 Are there any current or future factors that hindered or are likely to hinder achievement of these outcomes?



n=38

Source: ACIL Allen 2023 Survey of the astronomy sector

Other benefits enabled by AWLAI

36 respondents provided further comment to the question "To what extent do you agree that AWLAI is supporting other benefits, including:" (see Figure 4.16).

These free text format responses were qualitatively analysed, with the most common reply (5 responses) being that *ESO and astronomy in general is important for STEM engagement.* This was followed by 4 responses stating that *ESO provides good opportunities to move into industry.* Responses also noted that *ESO is a great organisation and Australia has the potential to play a* *huge role if we play our cards right* (2 responses). Numerous responses were reflected by only 1 respondent.

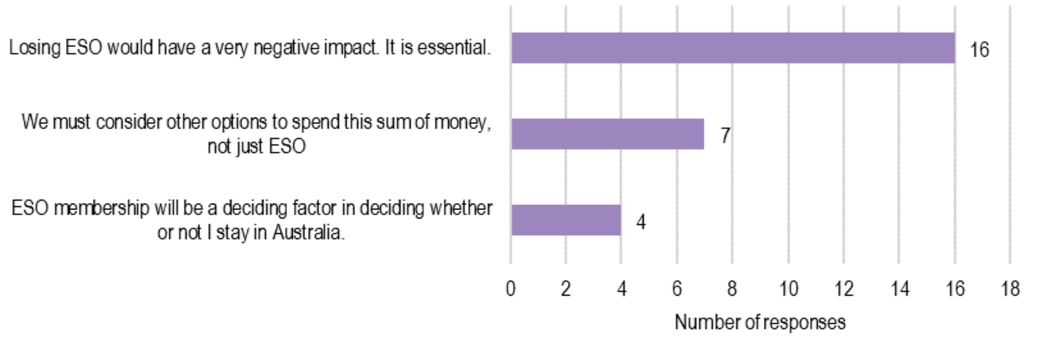
B.2.10 Final comments

Qualitative analysis of free text responses (see Figure B.39) shows that in the concluding remarks, respondents most commonly reported that *losing ESO would have a very negative impact* and that it is essential to their research or organisation. However, 7 respondents reported that other options should be considered.

> *Access to ESO facilities can still be achieved through either open sky policies or collaboration with European colleagues, therefore a serious consideration of the return on investment is warranted.*
>
> *Survey respondent*

Numerous perspectives were reported by only one respondent.

Figure B.39 Do you have any other comments you would like to make before concluding the survey?



n=32

Source: ACIL Allen 2023 Survey of the astronomy sector

B.3 Evaluation survey questions

Introduction

The 2017-18 Budget included funding for measures designed to maintain Australia's capability in optical astronomy (the Maintaining Australia's Optical Astronomy Capability (MAOAC) budget measure). The Access to World Leading Astronomy Infrastructure (AWLAI) program was created to implement this budget measure and support Australia's optical astronomy activities. A key element of the program is its support for Australia's 10-year strategic partnership with the European Southern Observatory (ESO). This partnership grants Australia access to the La Silla and Paranal Observatories (LPO) for 10 years from 2018. In February 2022, an amendment was made to the Australia-ESO Strategic Partnership Arrangement to allow Australian industry and astronomy institutions to tender for contracts under the ESO Technology Development Program.

AWLAI also transitioned Australia's existing research and commercial capabilities in the Australian Astronomical Observatory (AAO) from the Government to the research sector. This resulted in the separation of the AAO into the Anglo-Australian Telescope (AAT), operated by a consortium of universities and Astronomy Australia Limited (AAL), and created the astronomy instrumentation consortium, Astralis.

The stated purpose of AWLAI is to:

- Ensure continued Australian astronomy research excellence through access to world-leading infrastructure.
- Address critical challenges for Australia's optical astronomy community.
- Maintain and strengthen Australian expertise in optical astronomy research and development.
- Create new international contracting opportunities, new capabilities and enable exposure to sophisticated technology development for Australian business.

ACIL Allen is bound by confidentiality provisions and will ensure that all data collected during this evaluation meets the obligations set out in the Australian Privacy Principles. All parties operate in accordance with the *Privacy Act 1988*. Survey participants will not be personally identified as part of the evaluation process, including any reporting by ACIL Allen.

Privacy Collection Notice

I understand the terms outlined in the Privacy Collection Notice and agree to participate in the survey

Mandatory tick box

Tell us about your organisation

1. What is the name of your institute/organisation?

Tick one

- Australian National University
- Curtain University
- Macquarie University
- Monash University
- Swinburne University of Technology
- The University of Adelaide
- The University of Melbourne
- UNSW
- The University of Queensland
- University of Southern Queensland
- The University of Sydney
- University of Tasmania
- The University of Western Australia
- Western Sydney University
- Other: Please specify

European Southern Observatory (ESO) Strategic Partnership (SP)

2. Have you applied for observation time, in any role, on any ESO telescope through the ESO-SP?

Select one

- Yes
- No (move to next page)
-

3. Have you received any observation time, in any role, on any ESO telescope through the ESO-SP?

Select one

- Yes
- No

If yes:

a) How many hours of observation time have you received, in any role, on any ESO telescope?
Select one

- 0-20 hours
- 21-50 hours
- 51-100 hours
- More than 100 hours

b) Overall of your observation time allocations, were these programs:

Select one

- All complete
- Mostly complete
- Mostly incomplete
- Never executed

c) What other approaches or programs would you use if you did not have access to ESO Facilities and what would be the impact of this?

Free text

If no

d) Which of the following approaches, if any, have you used or do you intend to use to replace access to ESO?

Tick all that apply

- Modified my research project
- Relied on public AAT or ESO data
- Intending to reapply for ESO observation time
- Collaborated with researchers using ESO observation time
- Accessed AAT observation time
- Accessed other observatories: please specify
- Other: please specify

e) How did this impact your research?

Free text

Anglo Australian Telescope

4. Have you applied for observation time on the Anglo Australian Telescope (AAT)?

Select one

- Yes
- No (move to next page)

5. Have you received any observation time on AAT?

Select one

- Yes
- No

If yes:

a) How many hours of observation time have you received, in any role, on AAT?

Select one

- 0-20 hours
- 21-50 hours
- 51-100 hours
- More than 100 hours

b) Overall of your observation time allocations, were these programs:

Select one

- All complete
- Mostly complete
- Mostly incomplete
- Never executed

c) What other approaches or programs would you use if you did not have access to AAT and what would be the impact of this?

Free text

If no:

d) Which of the following approaches, if any, have you used or do you intend to use to replace access to AAT?

Tick all that apply

- Modified my research project
- Purchased observation time on AAT
- Relied on public AAT or ESO data
- Intending to reapply for AAT observation time
- Collaborated with researchers using AAT observation time
- Accessed ESO observation time
- Accessed other observatories: please specify
- Other: please specify

e) How did this impact your research?

Free text

6. To what extent do you agree that the following processes for accessing AAT facilities were clear/easy to follow:

Matrix question with Likert scale – strongly disagree, disagree, neutral, agree, strongly agree, unsure, not applicable

- Program guidelines
- Application form (e.g. the types of information requested)
- Online platform interface for submitting the application
- Feedback on the applications
- Reporting

7. Thinking about your experiences with AAT, to what extent do you agree with the following statements:

Matrix question with Likert scale – strongly disagree, disagree, neutral, agree, strongly agree, unsure, not applicable

- The effort of the AAT administration process was proportional to the size of the allocation
- Requests for information and reporting from AAT were reasonable
- Clear reasons were provided for program decisions/information requests by AAT
- The time between submitting a proposal/request to receiving a decision is reasonable

8. How could the AAT processes be improved and how important are these improvements to you?

   Free text

9. The Australian Government transferred management of the AAT to the AAT Consortium in 2018. To what extent did the following change during this transfer process:

   Matrix question: Increased, Decreased, Remained the same, Unsure

   – Your access to AAT
   – The quality of your AAT research
   – The impact of your AAT research
   – Overall access to AAT
   – The overall quality of AAT research
   – The overall impact of AAT research

   If selected that they received time on both AAT and ESO

10. To what extent does your access to AAT impact the success of your applications to ESO facilities?
    Tick one

   – Access to AAT improves my success in applying for ESO facility access
   – Access to AAT has no impact on my success in applying for ESO facility access
   – Unsure
   – Not applicable

   a) Please provide any further comments
      Free text

Square Kilometre Array (SKA) precursor telescopes

11. Have you received time on the Square Kilometre Array (SKA) precursor telescopes (ASKAP and Murchison Widefield Array)?

   Select one

   – Yes
   – No (move to next page)

   If selected that they received time on both AAT and SKA

12. To what extent have there been any synergies or additional benefit from accessing both the AAT and SKA precursor telescopes facilities?
    Free text

   If selected that they received time on both ESO and SKA

13. To what extent have there been any synergies or additional benefit from accessing both the ESO and SKA precursor telescopes facilities?
    Free text

Astronomy Australia Limited

14. a) Did AAL support you to access time on the following facilities?

   Matrix question: Yes, No, Not applicable

   – ESO
   – AAT

b) How important was that support to you? (Show if answered 14a ESO = Yes)

   Matrix question: Very unimportant, Unimportant, Neutral, Important, Very important, Not applicable

- ESO

— c) How important was that support to you? (Show if answered 14a AAT = Yes)

— *Matrix question: Very unimportant, Unimportant, Neutral, Important, Very important, Not applicable*

- AAT

15. How could AAL better support you in your astronomy research, and how important is this improvement to you?

Free text

Astralis

16. The Australian Government transferred management of the Australian Astronomical Optics facilities to Astralis in 2018. To what extent was Australia's instrumentation capability affected during the transfer process?

Select one

- Strongly reduced
- Somewhat reduced
- No change
- Somewhat increased
- Strongly increased
- Unsure

17. How could the Astralis better support you in your astronomy research, and how important is this improvement to you?

Free text

Departmental Industry Liaison Officer

18. Have you interacted with the Departmental Industry Liaison Officer (ILO) in any capacity?

Select one

- Yes
- No (move to next page)

19. Please describe your interaction with the ILO

— *Free text*

20. Did you achieve any outcomes as a result of your engagement with the ILO?

— *Free text*

Outcomes and impacts

21. To what extent do you agree that AWLAI is achieving its intended outcomes of increasing:

Matrix question: Strongly disagree, Disagree, Neutral, Agree, Strongly agree, Unsure

- Collaboration across the astronomy community and university sector in Australia
- Collaboration across the astronomy research and industry sectors in Australia
- Australian astronomers' level of international collaboration
- Australian astronomers' international competitiveness and reputation
-
- Australia's astronomy research excellence through access to world-leading infrastructure
- The quality of scientific output
- The quantity of scientific output

- Movement of international astronomers to Australia
- Retention of Australian astronomers in Australia
-
- Commercialisation of optical astronomy instruments and astronomy technology
- Commercialisation of optical astronomy technical expertise in other sectors
- Access to commercial tenders
- Success in being awarded commercial tenders
- a) Please provide the most significant examples you can think of:
- *Free text*

22. Would the outcomes you identified above have been achieved without AWLAI?

    Matrix question with Likert scale: 1 = I definitely would not have been able to achieve these impacts, 5 = I definitely would have been able to achieve these impacts, Not applicable, Not sure

23. Are there any current or future factors that helped or could help achieve these outcomes?

    Free text

24. Are there any current or future factors that hindered or are likely to hinder achievement of these outcomes?

    Free text

25. To what extent do you agree that AWLAI is supporting other benefits, including:

    Matrix question: Strongly disagree, Disagree, Neutral, Agree, Strongly agree, Unsure

    - Encouraging greater public engagement in STEM
    - Encouraging students to study STEM subjects
    - Creating skilled workers that move into other industries
    - Supporting open data sharing
    - Supporting standards and ethical review processes in astronomy
    - Other: please specify

    a) Please provide any further comments

    Free text

Concluding remarks

26. What are the implications of not acceding to full ESO membership (noting that the strategic partnership cannot be extended)?

    Matrix with Likert scale: Extremely negative impact, Negative impact, Neutral, Positive impact, Extremely positive impact

    - Impact on my ability to access world-leading facilities
    - Impact on the quality of my research
    - Impact on my ability to source and/or retain Australian talent
    - Impact on my ability to source and/or retain international talent
    - Impact on my ability to collaborate with researchers from ESO member states
    - Other: please specify

    a) Please provide further comments

    Free text

27. Do you have any other comments you would like to make before concluding the survey?

    Free text

Additional data and information C

C.1 Alignment of AWLAI to Government objectives

Table C.1 aligns the 5 key purposes of AWLAI (see section 1.1) with the Decadal Plan and Roadmap. This shows strong alignment of each AWLAI key purpose with the Decadal Plan and Roadmap.

Table C.1 AWLAI and ESO-SP priority alignment matrix with Decadal Plan 2016-2025 and National Research Infrastructure Roadmap

		AWLAI priorities					ESO-SP priorities	
		1 Ensure continued Australian astronomy research excellence through access to world-leading infrastructure	2 Address critical challenges for Australia's optical astronomy community	3 Maintain and strengthen Australian expertise in optical astronomy research and development	4 Create new international contracting opportunities, new capabilities and enable exposure to sophisticated technology development for Australian business	5 Deliver strong support for the Astronomy community and university sector	Provide access to 8m VLT telescope	Maintain a critical mass of world-leading astronomy and instrumentation expertise in Australia
Decadal Plan for Australian Astronomy 2016-2025	Partnership equating to 30% of an 8-metre class optical/infrared telescope	✓	✓	✓	✓	✓	✓	✓
	Continued development and operations of Square Kilometre Array (SKA) precursors, the Australian SKA Pathfinder (ASKAP) and Murchison Widefield Array (MWA) at the Murchison Radio-astronomy Observatory (MRO), and membership of the SKA telescope	✓	✓			✓		✓
	Partnership equating to 10% of a 30-metre class optical/infrared extremely large telescope (ELT), such as the Giant Magellan Telescope (GMT)	✓	✓	✓	✓	✓		✓
	Capability within the national observatories (the Australian Astronomical Observatory, AAO; and Australia Telescope National Facility, ATNF) to maximise Australia's engagement in global projects through instrumentation development for these and other facilities	✓	✓	✓	✓	✓		✓
	World-class high performance computing (HPC) and software capability for large theoretical simulations, and resources to enable processing and delivery of large data sets from these facilities.	✓	✓	✓	✓	✓		✓
2016 National Research Infrastructure	Enhance capability in optical astronomy and associated technologies by establishing a formal partnership in an 8-metre-class optical telescope, to maximise return on our investment in the GMT.	✓	✓			✓	✓	✓
	Maintain priority through full utilisation of the SKA precursor telescopes (ASKAP and MWA) to maximise the Australian benefit via technology development and scientific discovery during the construction of the SKA.	✓	✓	✓		✓		✓

Note: Blank sections denote a lack of clear alignment between priorities.
Source: ACIL Allen

C.2 Australian ESO User Survey (2019-2022)

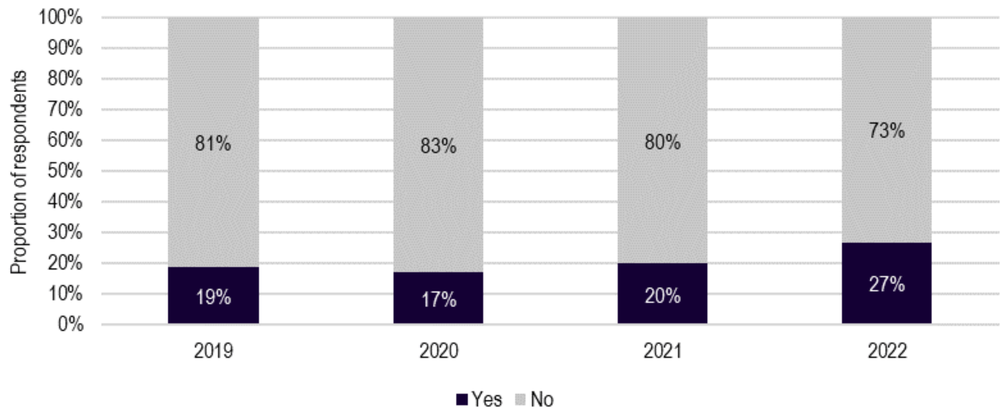
Overview of the data

Annual Australian ESO User Surveys were conducted by AAL in 2019 (16 responses), 2020 (24 responses), 2021 (15 responses) and 2022 (11 responses). AAL contacted PIs to gather feedback on their user experience. Responses to the same questions asked across each year are compared below to provide insights on ESO facility use, collaboration, research training and funding, and research outputs.

ESO use

The proportion of respondents who were using an overseas optical/infrared telescope as a PI for the first time has increased between 2019 and 2022. The most significant change was between 2021 and 2022, where the proportion of first-time users rose by 7%.

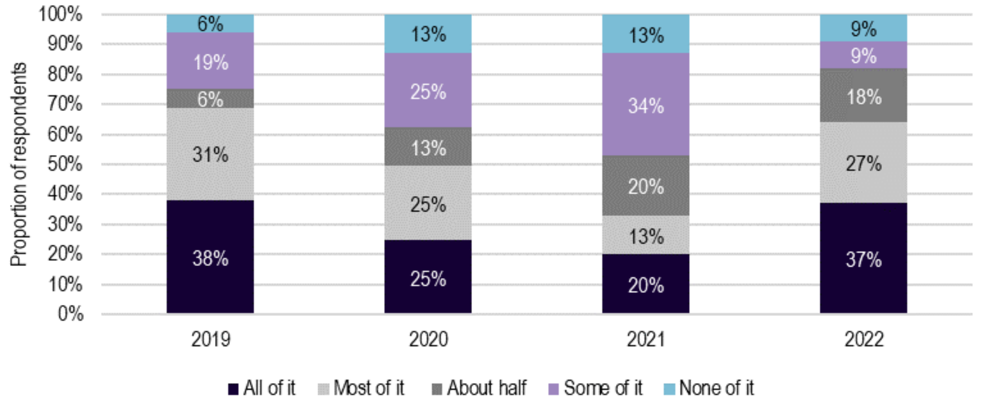
Figure C.1 Was this your first time accessing an overseas optical/infrared telescope as a PI?



Note: The number of responses to this question in each year is unknown. The total number of responses to the survey were as follows: 26 in 2019, 24 in 2020, 15 in 2021 and 11 in 2022.
Source: Australian ESO User Survey (2019-2022)

In terms of the proportion of allocated ESO time that was ultimately observed, and useful for their science, researchers most commonly answered 'all of it'. This proportion fell from 38% in 2019 to 20% in 2021 and recovered to 37% in 2022. The proportion of allocated ESO time that was ultimately observed and useful for the respondents' science was highest in 2019 and 2022. Noting that the total number of respondents varied, the increase may reflect changes induced by the COVID-19 pandemic.

Figure C.2 Considering all of your awarded programs, what fraction of your allocated ESO time was ultimately observed, and useful for your science?



Note: The number of responses to this question in each year is unknown. The total number of responses to the survey were as follows: 26 in 2019, 24 in 2020, 15 in 2021 and 11 in 2022.

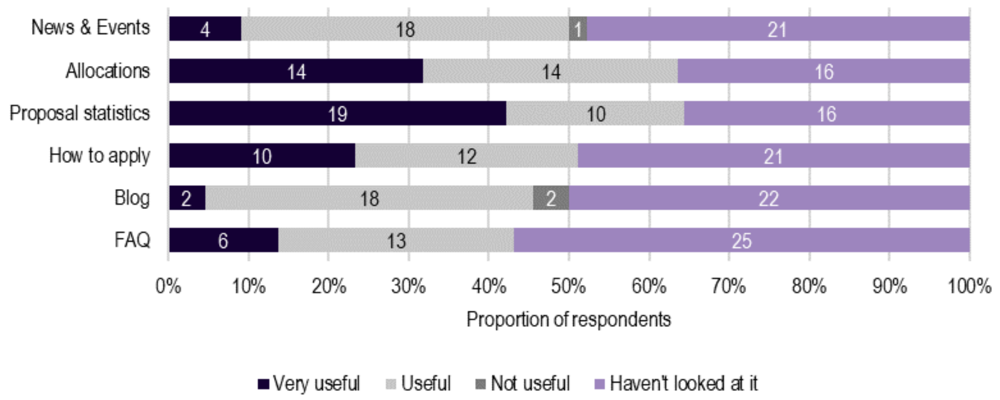
Source: Australian ESO User Survey (2019-2022)

Almost half of all respondents reported not having viewed sections of the ESO Users Forum, such as the FAQs, Blog, How to apply, Proposal statistics, Allocations, and News & Events.

Among respondents that did view these sections, 39% found these resources 'very useful', 59% found them 'useful' and only 2% found them 'not useful'.

The most useful sections were the Proposal statistics and Allocations sections.

Figure C.3 Usefulness of viewed ESO Users Forum sections



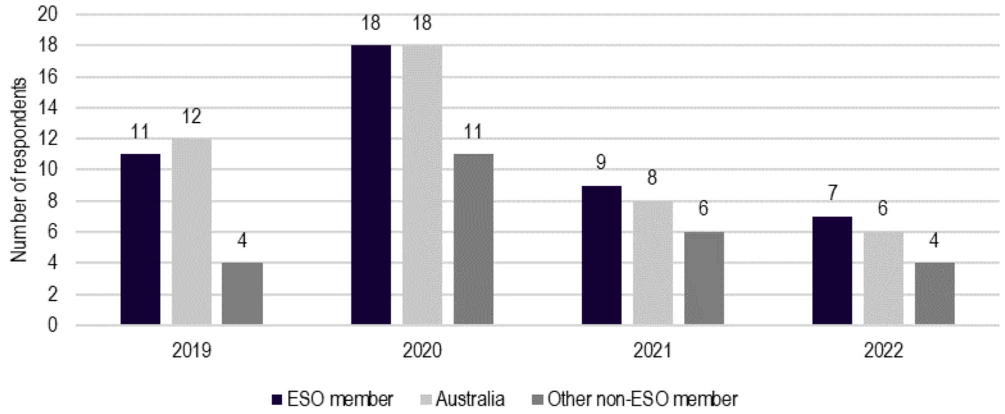
Note: The number of responses to this question in each year is unknown. The total number of responses to the survey were as follows: 26 in 2019, 24 in 2020, 15 in 2021 and 11 in 2022.

Source: Australian ESO User Survey (2019-2022)

Collaborations, research training and funding

Between 2019 and 2022, ESO access enabled or fostered similar numbers of new collaborations with astronomers in both Australia and countries that are ESO members, with fewer collaborations made with other non-ESO members. Noting that the total number of respondents varied, the increase in new collaborations in 2020 may reflect changes induced by the COVID-19 pandemic.

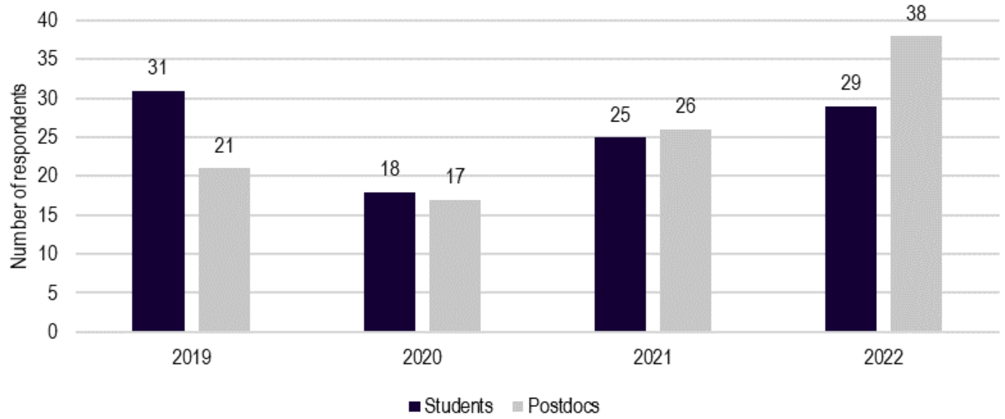
Figure C.4 Has this ESO access enabled or fostered new collaborations with astronomers from any of the following countries?



Note: The number of responses to this question in each year is unknown. The total number of responses to the survey were as follows: 26 in 2019, 24 in 2020, 15 in 2021 and 11 in 2022.
Source: Australian ESO User Survey (2019-2022)

The number of Australian students and postdoctoral fellows varied across years, noting that the total number of respondents also varied. The number of students in 2022 represents a more significant increase due to the lower number of responses in 2022.

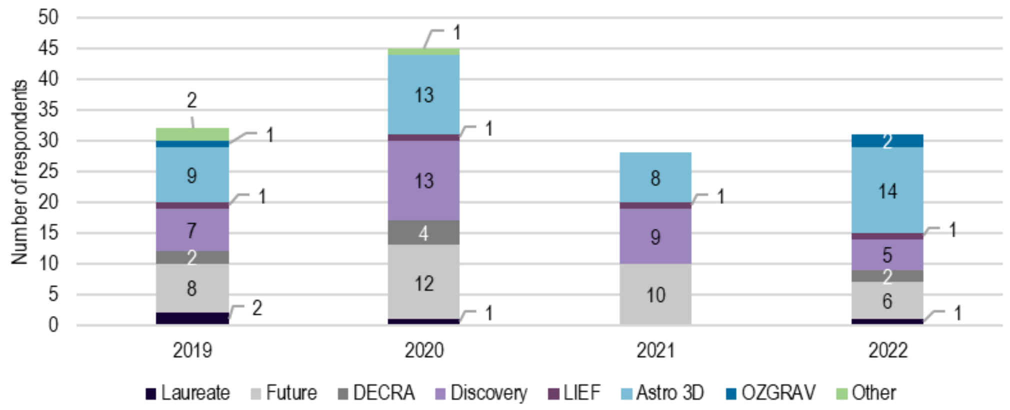
Figure C.5 How many Australian students and postdoctoral fellows (yourself included, if applicable) will benefit from working with your ESO data?



Note: The number of responses to this question in each year is unknown. The total number of responses to the survey were as follows: 26 in 2019, 24 in 2020, 15 in 2021 and 11 in 2022.
Source: Australian ESO User Survey (2019-2022)

Between 2019 and 2022, the ARC-funded research grants that most commonly helped, supported or directly benefited respondents' ESO usage were Future Fellowships, Discovery Grants and ASTRO 3D COE grants.

Figure C.6 Between you and your Co-Investigators, how many of the following types of ARC-funded research grants have either helped support, or will directly benefit from, your ESO usage?



Note: Laureate: Australian Laureate Fellowships, Future: Future Fellowships, Discovery:Discvoey Projects, DECRA: Discovery Early Career Researcher Award, LIEF: Linkage Infrastructure, Equipment and Facilities, Astro 3D: ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions, OZGRAV: Centre of Excellence for Gravitational-Wave Discovery.

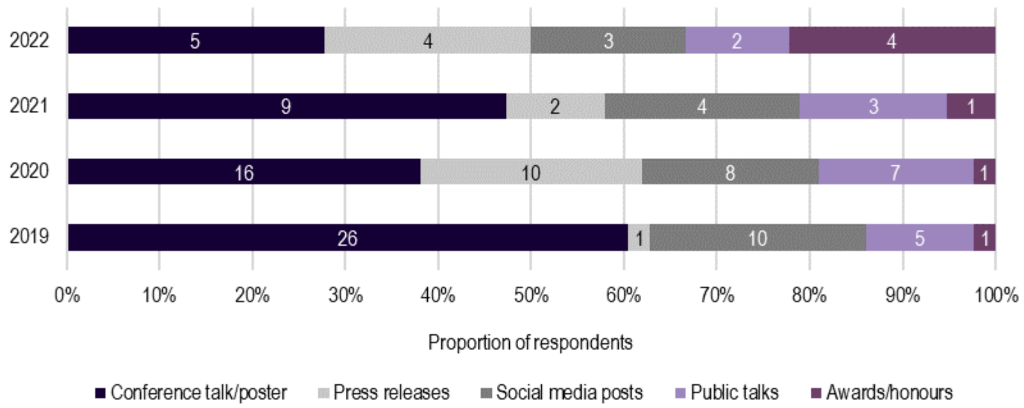
Note: The number of responses to this question in each year is unknown. The total number of responses to the survey were as follows: 26 in 2019, 24 in 2020, 15 in 2021 and 11 in 2022.

Source: Australian ESO User Survey (2019-2022)

Research outputs

The most common outputs and activities reported from respondents' ESO usage were conference talks/posters and social media posts, for all years.

Figure C.7 How many of the following outputs and activities have you undertaken in the past 12 months as a result of any recent ESO usage?

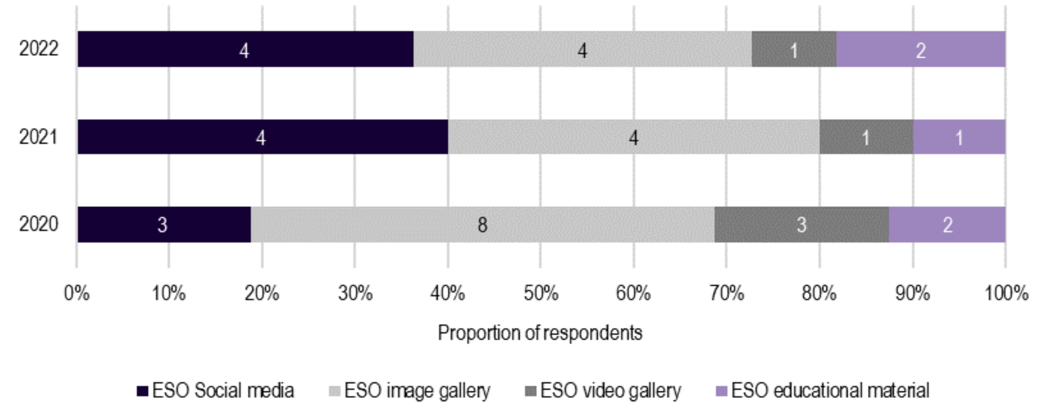


Note: The number of responses to this question in each year is unknown. The total number of responses to the survey were as follows: 26 in 2019, 24 in 2020, 15 in 2021 and 11 in 2022.

Source: Australian ESO User Survey (2019-2022)

The most common ESO outreach resource used by respondents between 2020 and 2022 were the ESO image gallery and ESG social media.

Figure C.8 Have you made use of any of the following ESO outreach resources?



Note: The number of responses to this question in each year is unknown. The total number of responses to the survey were as follows: 26 in 2019, 24 in 2020, 15 in 2021 and 11 in 2022.

Source: Australian ESO User Survey (2019-2022)

Benefits from the ESO-SP

Other tangible benefits stemming from the ESO-SP that were identified by survey respondents include access to state-of-the-art telescopes and equipment (6 responses), greater collaboration and partnerships (4 responses), increased opportunities for leadership (2 responses), improved employment prospects (3 responses), as well as the ability to think and plan at a bigger scale (1 response).

Least satisfactory, or most frustrating aspect of ESO user experience

Frustrating aspects of the ESO user experience identified by survey respondents included telescope closures and delays (3 responses). They also mentioned issues such as data retrieval challenges (4 responses) non-expert comments (1 response), difficulty in optimising for faint targets due to limited General Observing Constraints (1 response), difficulty in accessing engineering data (1 response), a lack of transparency in ESO decisions, the need for better oversight of time allocation committees (1 response). Additionally, an astronomer noted struggling with defining observation criteria (1 response), while another expressed frustration to a change in the method of preparing observing blocks, which are structured sets of information and commands to the telescope (1 response).

C.3 Australian ESO Outcomes

Overview of the data

AAL collects insights on Australian ESO outcomes, including time requested/allocated and the distribution of time allocated to different institutions and instruments.

Reporting was conducted for each ESO semester from 101-111, excluding semester 107, in which no Australian-led proposals were awarded time. This resulted from delays in previous semesters caused by the COVID-19 pandemic. Semesters span 6-months (see Table C.2).

Table C.2 Start and end dates of semesters 101-111

Semester	Start	End
101	Apr-18	Sep-18
102	Oct-18	Mar-19
103	Apr-19	Sep-19
104	Oct-19	Mar-20
105	Apr-20	Sep-20
106	Oct-20	Mar-21
107^	Apr-21	Sep-21
108	Oct-21	Mar-22
109	Apr-22	Sep-22
110	Oct-22	Mar-23
111	Apr-23	Sep-23
112	Oct-23	Mar-24

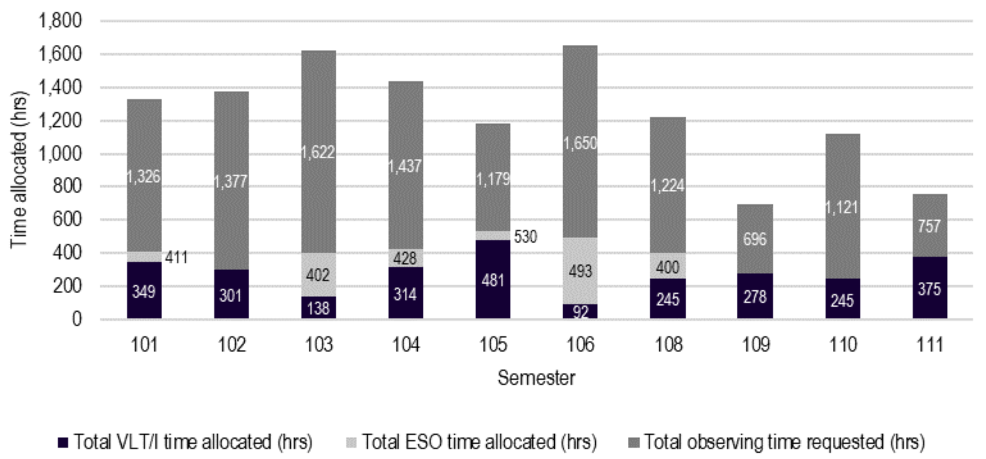
Note: ^No Australian-led proposals were awarded time in semester 107. COVID-19 caused a backlog in preceding semesters, which caused ESO to halt standard calls for proposals for semester 107.

Source: Australia outcomes ESO Period 101-111

Australian-led ESO proposal summary

Figure C.9 shows the total observing time requested by universities, and the ESO and VLT/I time allocated. Semester 106 had the most requested observing time (1,650 hours), while semester 105 had the largest number of hours of allocated ESO time (530 hours) and largest proportion of total ESO time allocated relative to time requested (45%). The semesters with the lowest proportion of hours allocated to hours requested were semester 102 and semester 110 (22%).

Figure C.9 Total observing time requested, ESO time allocated, and VLT/I time allocated



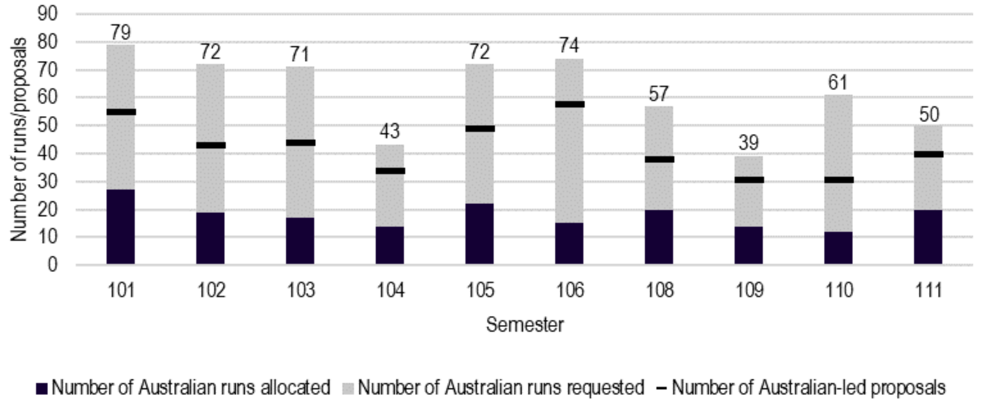
Note: No Australian-led proposals were awarded time in semester 107. COVID-19 caused a backlog in preceding semesters, which caused ESO to halt standard calls for proposals for semester 107.

Source: Australia outcomes ESO Period 101-111

The highest number of runs requested was in semester 101 (79), and the fewest in semester 109 (39). Semester 111 had the highest proportion of runs allocated (40%). Semester 106 and semester 110 had the lowest proportion of runs allocated (~20%).

Semester 106 contained the highest number of Australian-led proposals (58), while semester 109 and semester 110 each had the fewest number of Australian-led proposals (31).

Figure C.10 Number of Australian runs requested, allocated and number of Australian-led proposals

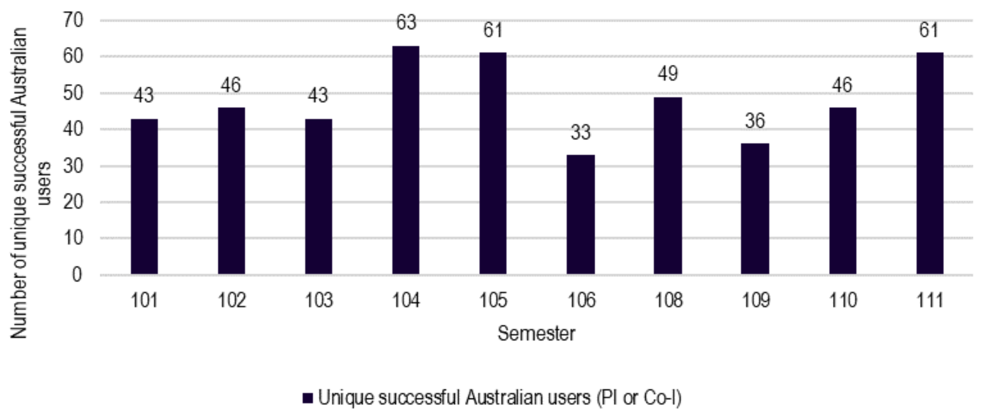


Note: No Australian-led proposals were awarded time in semester 107. COVID-19 caused a backlog in preceding semesters, which caused ESO to halt standard calls for proposals for semester 107.

Source: Australia outcomes ESO Period 101-111

Semester 104 had the most unique successful Australian users (63), both PI and Co-I. Semester 106 had the fewest (33).

Figure C.11 Unique successful Australian users, both PI and Co-I, by semester

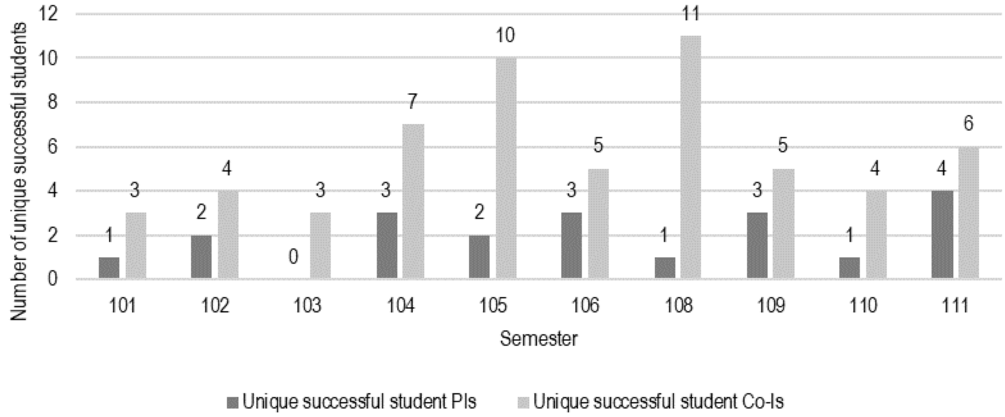


Note: No Australian-led proposals were awarded time in semester 107. COVID-19 caused a backlog in preceding semesters, which caused ESO to halt standard calls for proposals for semester 107.

Source: Australia outcomes ESO Period 101-111

Semester 105 had the highest number of unique successful student Co-Is (10) and semester 111 the most unique successful student PIs (4).

Figure C.12 Number of unique successful student PIs and Co-Is, by semester



Note: No Australian-led proposals were awarded time in semester 107. COVID-19 caused a backlog in preceding semesters, which caused ESO to halt standard calls for proposals for semester 107.

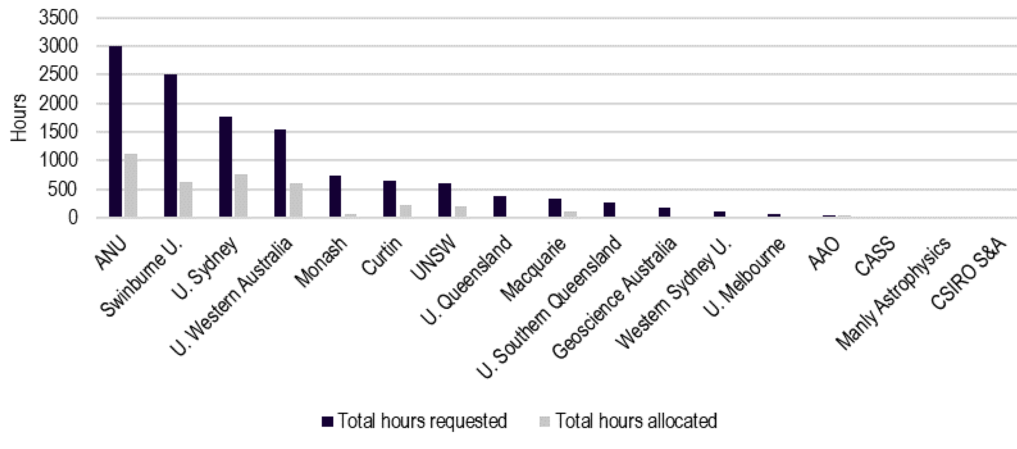
Source: Australia outcomes ESO Period 101-111

PI Allocations by institution

ANU requested (2,998 hours) and was allocated (1,117 hours, 47%) the largest number of hours. Manly Astrophysics requested the fewest number of hours (16 hours requested and 0 allocated).

Western Sydney University (119.9 hours), Geoscience Australia (177.4) hours and CASS (26 hours), also requested hours, yet were not allocated any. CSIRO S&A did not request or receive any hours.

Figure C.13 Hours requested and allocated by institution from semesters 101-111, cumulative



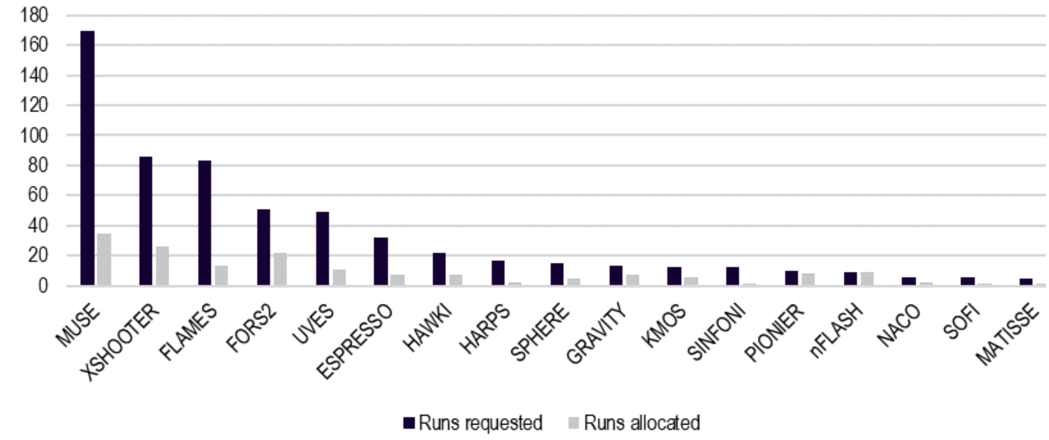
Note: No Australian-led proposals were awarded time in semester 107. COVID-19 caused a backlog in preceding semesters, which caused ESO to halt standard calls for proposals for semester 107. This includes Large Programme/Monitoring reallocations between semesters.

Source: Australia outcomes ESO Period 101-111

PI Allocations by instrument

The MUSE telescope had the highest number of runs requested (170 runs) and allocated (35 runs). This was followed by XSHOOTER with the second most runs requested (86 runs) and allocated (26 runs).

Figure C.14 Runs requested and allocated by instrument from semester 101-111, cumulative



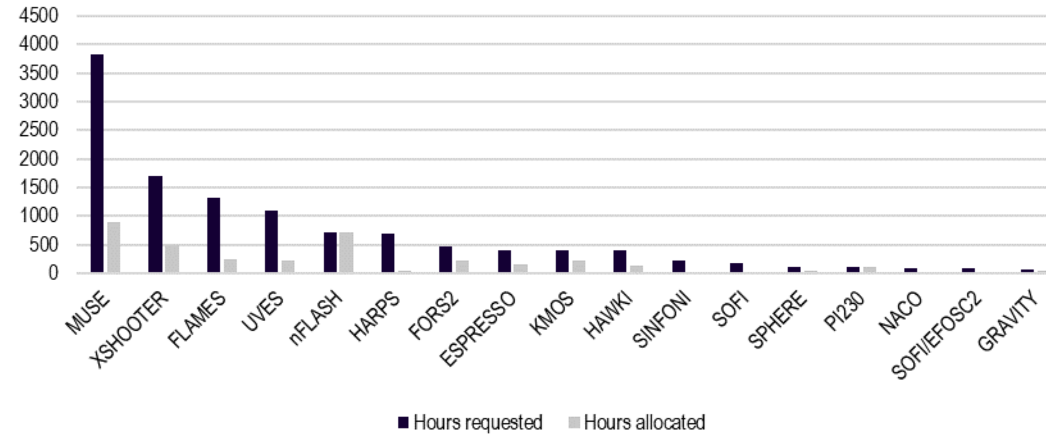
Note: No Australian-led proposals were awarded time in semester 107. COVID-19 caused a backlog in preceding semesters, which caused ESO to halt standard calls for proposals for semester 107. This includes Large Programme/Monitoring reallocations between semesters.

The following instruments have <5 runs requested between semesters 101-111 so were not included in this graph: SOFI/EFOSC2, CRIRES, EFOSC2, VISIR, VISITOR, ARTEMIS, OMEGA, CAMPI230, SEPIA180, AMBER, CONCERTO, LASMA, NIRPS, VIMOS, VIRCAM.

Source: Australia outcomes ESO Period 101-111

The MUSE telescope had the most hours requested (3823 hours) and allocated (882 hours). This was followed by XSHOOTER, with the second most hours requested (1707 hours) and allocated (487 hours).

Figure C.15 Hours requested and allocated by instrument from semesters 101-111, cumulative



Note: No Australian-led proposals were awarded time in semester 107. COVID-19 caused a backlog in preceding semesters, which caused ESO to halt standard calls for proposals for semester 107. This includes Large Programme/Monitoring reallocations between semesters.

The following instruments have <60 hours requested between semesters 101-111 so were not included in this graph: PIONIER, EFOSC2, MATISSE, ARTEMIS, VISITOR, VISIR, CRIRES, OMEGACAM, SEPIA180, AMBER, CONCERTO, LASMA, NIRPS, VIMOS, VIRCAM

Source: Australia outcomes ESO Period 101-111

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