AAT and SSO: White Paper on Future Options

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Executive Summary

By the end of the 2016-2025 Astronomy Decadal Plan, the Anglo-Australian Telescope (AAT) will have been operating continuously for half a century. It has served, and continues to serve, the Australian community extremely well, though in recent years subscription factors, scientific productivity as measured by paper output, and funding have all been declining.

Over the first four years of the 2016-2025 Decadal Plan, data collected at the AAT have been used to address all six of the fundamental scientific questions that form the focus of the Plan, and it will continue to make contributions to these questions over the lifetime of the Plan.

The current level of funding ($3.2M per annum, plus $0.5M per annum from selling time, plus a Commonwealth grant for $1.6M over four years) is only just sufficient to operate and maintain the AAT. It allows for little or no contingency to deal with major failures, which are seen as probable for a facility of its age. This is the single biggest risk to operations.

It is anticipated that without new, or refurbished instruments, the user base will narrow, interest in using the AAT will diminish, funds for operations will be more difficult to source, and the scientific productivity of the facility will decline at an accelerating rate.

The challenge moving forward will be to identify the right mix of funding (national, international, and/or non-traditional sources) and access (to those who provide the funds) to ensure that the AAT continues to have a productive scientific future beyond 2025 and is seen to provide good value-for-money in the broader context of other Australian astronomy facilities.

In particular, decisions on the future scientific use of the AAT need to consider other facilities available at Siding Spring Observatory (SSO) and elsewhere. The need for rapid follow-up of sources discovered by LIGO, LSST, and SKA precursors and continuous monitoring of other sources is an area where SSO has a natural advantage, due to its geographical location.

Introduction

The Decadal Plan for Australian astronomy 2016-2025 foresaw the role of the AAT evolving significantly over this period.

“The Decadal Plan anticipates that facilities such as the AAT, the Parkes telescope and the ATCA may no longer be operated as national facilities by 2025 when their scientific capabilities are increasingly superseded by the next generation of optical/IR and radio telescopes.”

We are now four years into the plan and a mid-term review of the plan commenced in 2019.

A number of key priorities for the Decadal Plan are now in place. In 2017, the Australian Government and the European Southern Observatory (ESO) signed a 10-year strategic partnership, providing Australian astronomers with access to what is arguably the most advanced suite of 8m-class astronomical instrumentation on the planet.

In 2018, the responsibility for funding operations of the Anglo-Australian Telescope (AAT) transferred from the Australian Government to a consortium of 13 Australian universities. However, the AAT continues to be a national facility, in the sense that it is open to all astronomers based at an Australian institution.

The Decadal Plan also notes that "By 2020, strategies must be in place to transition current domestic facilities such as the Parkes telescope, ATCA, and the AAT to new roles within the ELT and SKA era, or to prepare for closure."

What is the scientific future of the AAT? It seems clear that without new or refurbished instruments, the user base will narrow, interest in using the AAT will diminish, and the scientific productivity of the facility will quickly decline.

To understand what this future might be, and to stimulate discussion within the Australian astronomical community, a series of town hall meetings were held in Perth, Brisbane, Sydney, Canberra, Hobart and Melbourne over a period of two weeks during the middle of September 2019. This paper summarises the results of these meetings.

First, we give an overview of the AAT, examining how operations changed when the AAT transitioned from the AAO to the universities. We also give an overview of Siding Spring Observatory, noting that over half the costs required to run the shared facilities of the Observatory are provided by the funders of the AAT. We then examine the demand for the AAT, compare its scientific productivity with other similar facilities overseas, examine how data from the AAT has been used to address the fundamental questions posed in the Decadal Plan, and finish with a number of possible scenarios for the future of the AAT.

Anglo-Australian Telescope

The 3.9m AAT is Australia's largest optical/infrared telescope. Commissioned in 1974, it served the Australian and British astronomical communities for over 30 years. In 2010, it became 100% Australian owned and operated. On 1 July 2018 the AAT transferred from being funded and operated by the Australian Astronomical Observatory to being funded by a consortium of 13 Australian universities (the AAT Consortium) and operated on behalf of the consortium by the ANU. The financial arrangements between the consortium members and the ANU are managed by Astronomy Australia Limited.

The AAT Consortium provides $3.175M per annum for telescope operations. (Prior to the transition, the running cost of the AAT was around $4M per annum).

The level of funding from the AAT Consortium is expected to continue at the current level until June 2022. In 2021, Astronomy Australia Limited (as Manager of the AAT Consortium)

will conduct a review of operations and explore options for future operations for at least the period 1 July 2022 to 30 June 2025.

Additional funds are available from two sources.

- Selling time on the telescope. To date, about $1M of telescope time has been sold. This time is spread out over the next 4 semesters.
- $1.6M in grant funding from the Department of Industry, Innovation and Science to fund a number of projects and to ensure continuity of service. Examples include the replacement of the dome bus bars and replacement of corroded elements in the HERMES cryostats. The grant ends in June 2022.

In the current operations model these additional funds are essential for the operation and maintenance of the telescope and its instruments.

To fit the new funding arrangements under the AAT Consortium, the following changes were made on 1 July 2018:

- no astronomical support (previously there was 3 FTE of astronomical support);
- no support to develop data reduction recipes or pipelines;
- service mode discontinued;
- reduction from 23 to 16 FTE of technical support
- on-call support discontinued;
- travel support restricted to students; and
- instrument changes restricted to Mondays, Tuesdays and Wednesdays only.

Steps taken to mitigate the productivity impact of that the reduced level of support include:

- contracting astronomers to provide astronomical support on a casual basis for some paid-time programs, and for programs awarded time through the CTIO-AAT time-swap arrangement;
- entering into an engineering and technical services support contract with AAO-MQ;
- implementing a much tighter acceptance policy to ensure that new instruments do not require significant observatory resources;
- requiring programs given large program status to keep instrument user manuals up to date, to monitor instrument performance and to contribute to the development of data reduction pipelines; and
- requesting proposal writers to describe the experience and expertise they have in using the instruments they request.

Siding Spring Observatory

Siding Spring Observatory (SSO) is Australia's largest optical/infrared astronomical observatory. Established in the 1960s, it is home to the 3.9m Anglo-Australian Telescope (AAT), the ANU's 2.3m telescope, SkyMapper, the UK Schmidt Telescope, and numerous other telescopes that are operated by national and international organisations. The list of operational telescopes at SSO is shown in Table 1.

The SSO site is managed by the Facilities & Services Division of the ANU. Site costs are around $700k per annum. 67% of SSO site costs are covered by the AAT. It is anticipated that this will come down to 50% by 2023.

Telescope	Operator	Comment
AAT	ANU (funded by consortium of Australian universities)	Owned by Commonwealth; open access for Australian-based astronomers
2.3m	ANU	Owned by ANU; open access for Australian-based astronomers
SkyMapper	ANU	Owned by ANU; early access to survey data for Australian-based astronomers
UKST	ANU (funded by Taipan/Funnelweb teams)	Owned by ANU; Australian-based astronomers can join survey teams
Faulkes	Las Cumbres Observatory	=LCO
LCO 1m	Las Cumbres Observatory	2 telescopes
LCO 0.5m	Las Cumbres Observatory	2 telescopes
JAXA	Japan Aerospace Exploration Agency	3 telescopes
KMTNet 1.6m	Korean Astronomy and Space Science Institute	
PROMPT	University of North Carolina at Chapel Hill	Several telescopes in a single dome
Huntsman	Macquarie University	Camera array
HAT South	HAT South Collaboration	2 camera arrays
iTelescope	iTelescope NET	Commercial organisation with 20 telescopes
bRing	bRing consortium	
Project Solaris	Nicolaus Copernicus Astronomical Center	
Veloce-RAPTOR	*Macquarie University*	*Operational in 2020*

Table 1: Telescopes at SSO. Telescopes in red are part of global networks. Decommissioned telescopes are not included (16", 24", 40", ROTSE, APT, Uppsala Schmidt).

SSO offers consortia a relatively cheap and well established location at which to site telescopes. Five international organisations (LCO, PROMPT, Project Solaris, KMTNet and HAT South – listed in red in Table 1) have based their telescopes at SSO because of the need to have 24-hour coverage of targets that are visible from the southern hemisphere.

With the advent of the Large Synoptic Survey Telescope (LSST) and Advanced LIGO, we foresee that there will be an increased need for rapid follow-up targets discovered by these two facilities. Interest in establishing new facilities at SSO to do exactly that has been expressed by a number of consortia.

The capacity to follow targets of interest (commonly referred to as Targets of Opportunity or ToOs) at short notice and automatically, and to process the data obtained immediately, are essential if SSO is to be competitive in this sphere. It is the driving reason for automating the 2.3m, which is seeing declining usage. The AAT is currently not well equipped to follow ToOs. The instrument of choice may not be available as instruments are tied to specific top ends, and the wrong top end may be mounted. Furthermore, an instrument, even if available, may not be

configured with the appropriate gratings at the time the request is received, implying a delay while the instrument is reconfigured manually.

SSO also offers instrument builders a relatively cheap, established location from which to test concepts and install novel instrumentation. Recent examples include HIPPI2 and PRAXIS on the AAT and the IR Lucky Imager on the 2.3m. Examples of SSO instruments that led to instruments on larger telescope include the fibre positioner that was used for the RAVE survey and the TAIPAN 'starbugs' positioner that will be used for MANIFEST on GMT.

The experience of other 4-metre-class telescopes

Over the past 20 years, there has been a gradual evolution towards increased specialisation, fewer top-end changes, and fewer instruments on the equatorial 4-metre-class telescopes that were built in the 1970s. Examples include:

- HARPS as the only instrument on the ESO 3.6m at La Silla, which has a mixture of regular PI and large programs;
- DESI as the only instrument on the Mayall at Kitt Peak, which will be dedicated 100% to surveys; and
- DECam as almost the only instrument used on the Blanco at CTIO, with 90% of time dedicated to DECam.

Apart from the AAT itself, the other counter-example is CFHT, which offers 5 instruments in queue mode; 60% of the time is dedicated to large programs and 40% to investigator-led programs.

The AAT currently offers 4 instruments (2dF+AAOmega, 2dF+HERMES, KOALA, and Veloce), 3 different top ends (2dF, f/8 and f/15) and allows visitor instruments. A fifth instrument, Hector will be commissioned in 2020 and the auxiliary Veloce-RAPTOR telescope will also come online to feed Veloce in 2020.

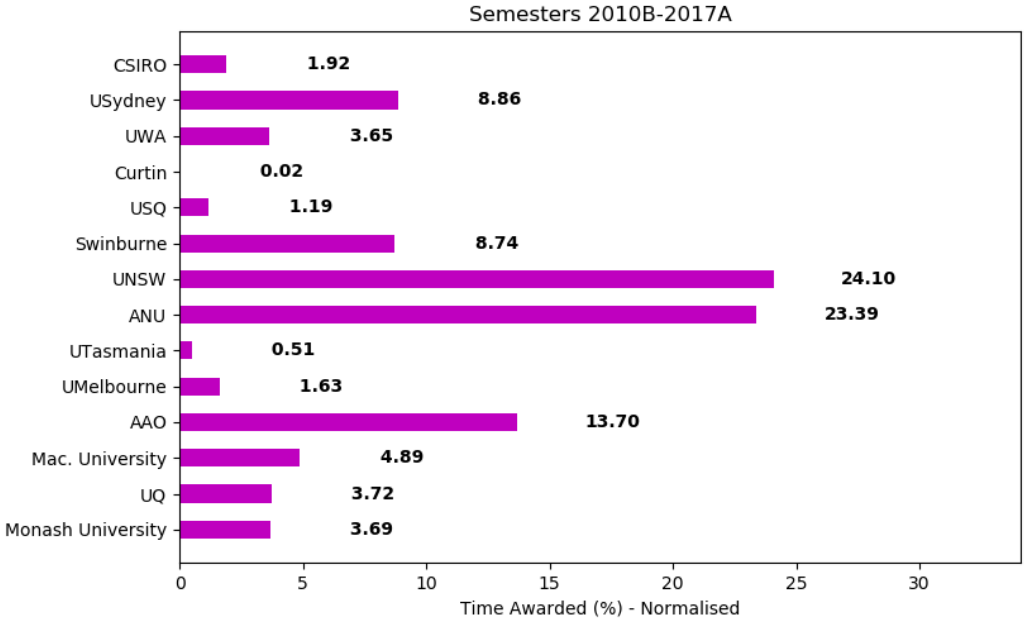
Specialisation is also occurring at 4-metre-class telescopes (all alt-azimuth) built *after* 1980.

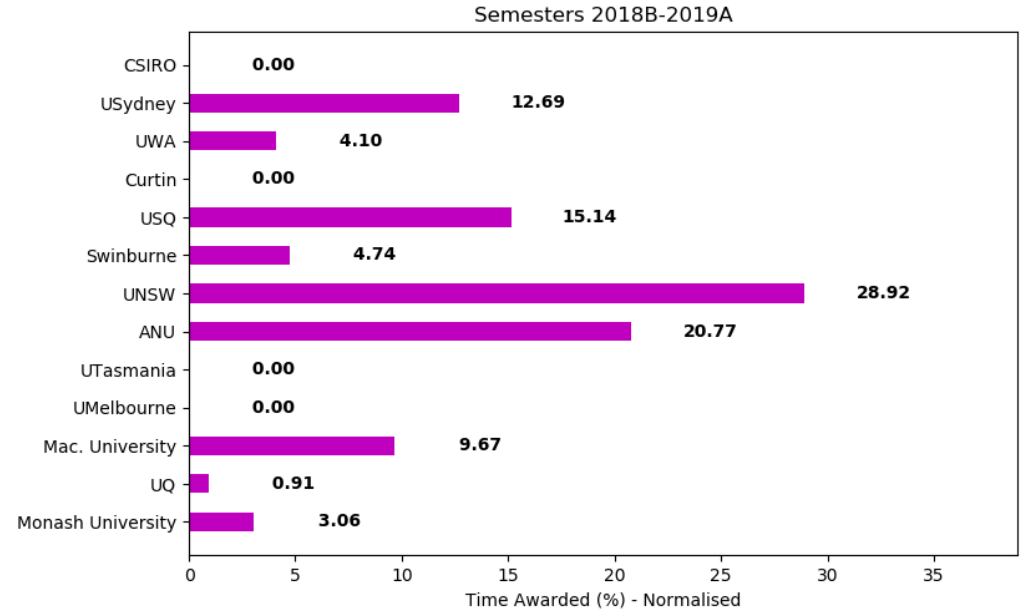
- WEAVE on WHT (La Palma), where 70% of the time on the telescope will be allocated to WEAVE to do dedicated surveys;
- SOXS (Son of X-Shooter) on NTT in 2022 (La Silla), and
- VIRCAM on VISTA (Paranal), which is dedicated 100% to public surveys. In early 2023, VIRCAM will be replaced by 4MOST, which will also be dedicated 100% to public surveys.

The AAT budget is one half to one third of the budget available to comparable 4-metre-class facilities overseas, such as CFHT and Blanco, and is comparable to budget to run the 3.5-meter at Calar Alto. However, comparisons can be misleading as some overseas facilities have budgets that support active instrument development teams and staff astronomers; the AAT budget includes neither.

Current Usage and Scientific Productivity

The AAT is used by a broad section of the Australian astronomical community. The following figure shows AAT usage by Australian-based astronomers from 2010B to 2017A (14 observing semesters). All members of the AAT consortium were allocated time in the AAT. A second figure shows usage during the last two observing semesters (2018B and 2019A). In the second figure, AAO and Macquarie University are counted as one organisation.





Between 2001 and 2003, the AAT was considered the most productive 4-metre-class telescope in the world. Productivity since then (as measured by the number of papers published each year and the impact of these papers) has declined. Between 2013 and 2017, the productivity was below that of some comparable 4-metre-class telescopes (e.g. CFHT, Blanco, Mayall, ESO NTT, ESO 3.6m, VISTA, WHT, UKIRT, IRTF), but above that of others (TNG, WIYN and SOAR).

The subscription factor (the amount of time requested divided by the amount available) is around 2.0 and has been around that level in recent years; between 2010 and 2015, it was around 2.5.

Six fundamental astronomical questions

The Decadal Plan lists six fundamental science questions to be addressed by Australian astronomers. Recent, current, and future AAT programs are making significant contributions to all six questions. Notably, these contributions largely come from AAT Large Programs.

1. How did the first stars and galaxies transform the Universe?

   The AAT is not well suited to detect the first galaxies. This question will be tackled with space-based facilities and with the extremely large telescopes now under construction. However, the GALAH survey, which uses 2dF and HERMES on the AAT, is obtaining kinematic and abundance information for a million stars in our galaxy, thus enabling us to examine how the first stars contributed to the enrichment history of the stars that we see today.

2. What is the nature of dark matter and dark energy?

   OzDES, which used 2dF and AAOmega, recently completed a six-year program to obtain redshifts of galaxies that hosted Type Ia supernovae in the 10 deep fields of the Dark Energy Survey. Results from a subsample of the data obtained by OzDES already provide constraints on the nature of dark energy that are as tight as any published. Constraints from the full OzDES data set will be even tighter. OzDES is a template for future similar surveys, such as TIDES, which will use 4MOST on the VISTA telescope in Chile. The ongoing S5 survey, which uses 2dF and AAOmega, is characterising the nature of dwarf galaxies in the halo of our galaxy. Dwarf galaxies are prime candidates for dark matter searches.

3. How do galaxies form and evolve across cosmic time?

   Through recent surveys such as GAMA and SAMI, through ongoing surveys, such as DEVILS, and through future surveys such as HECTOR, the AAT has played and will continue an important role in addressing this question.

4. How do stars and planets form?

   The newly commissioned Veloce instrument on the AAT is currently monitoring candidate planets that have been discovered with the TESS satellite. It follows a long tradition at the AAT, with the Anglo-Australian Planet Search monitoring stars for exoplanets using the radial velocity technique for just over 15 years from 1998 onwards. The demand for time on instruments like Veloce is currently high (thanks to the TESS mission and the paucity of other southern facilities form planet follow-up) and likely to remain so into the foreseeable future, as PLATO (an ESA medium class mission) goes into operation in the late 2020's.

5. How are elements produced by stars and recycled through galaxies?

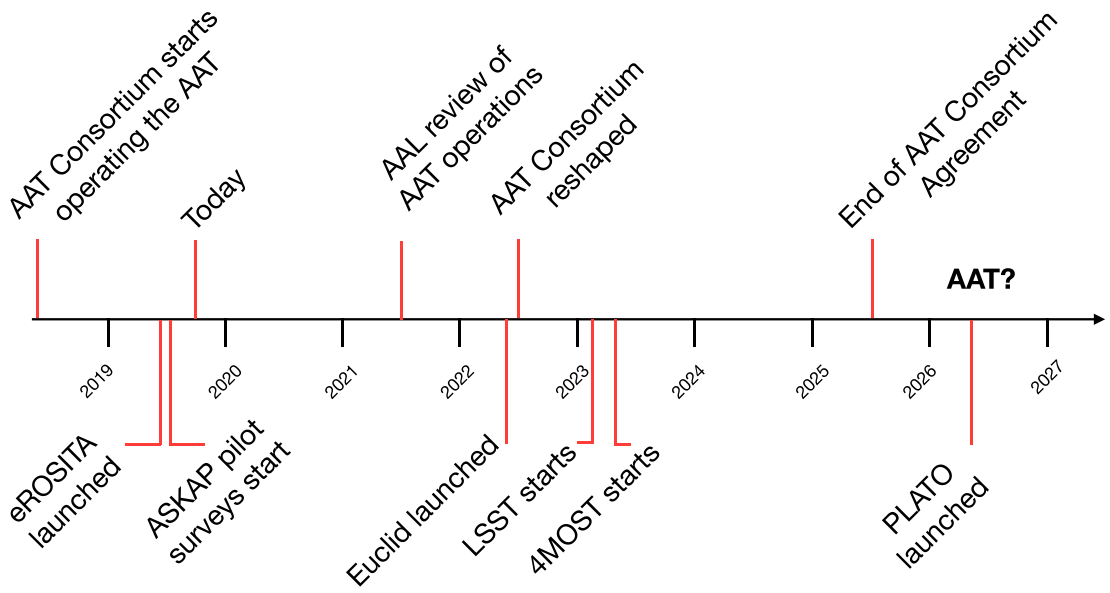
The AAT has played and will continue to play an important role in this field. both through the study of stars and dwarf galaxies in the halo of our own Galaxy via the GALAH and S5 surveys, respectively, and through the study of galaxies both near and far in the SAMI, HECTOR and DEVILS surveys.

6. What is the nature of matter and gravity at extreme densities?

   While the AAT is currently not well suited for rapid follow-up of interesting phenomena (This is presently a capability better handled by the ANU 2.3m telescope) the AAT was used to obtain a spectrum of the first electromagnetic counterpart to a gravitational wave event.

The Future of the AAT

There are two timeframes that should be considered: the more immediate time frame, up to 2025 (which includes the start of operations with LSST and 4MOST and the launch of Euclid) and the more distant time frame, 2025 and beyond. A graph illustrating these timeframes and how they fit in with the start of other major facilities is shown below.



To understand what the future of the AAT might be, and to stimulate discussion within the Australian astronomical community, a series of town halls were held in Perth, Brisbane, Sydney, Canberra, Hobart and Melbourne over a period of two weeks during September 2019.

A large number of views were expressed at these meetings. We encapsulate the views through six scenarios. There were some common elements in the discussions.

- Selling time on the AAT was seen as a useful way to defray the cost of operations. The current level (set to around 10% of the telescope time) was not seen by most as too high. Selling 50% of the time (if the current price were maintained) would increase the subscription factor to more reasonable levels, and largely defray the cost of operating the facility. However, it is unclear if there would be enough interest in the market place.

Some thought that 50% was too high and would not allow enough time to Australian astronomers, but there is clearly room to increase the fraction of time sold above the current level.

- Refurbishing 2dF so that it lasts until the end of the Decadal Plan (which also corresponds to 7 years after the transition to the new funding arrangement) was seen as essential by the majority of astronomers that attended the town hall meetings. 2dF *must* be operated for at least 2 years in order to meet commitments to the GALAH and DEVILS surveys and one of the clients buying AAT time.
- The set of Large Programs should involve as much of the Australian astronomical community as is reasonably practicable, otherwise the support for continued operations of the AAT may reduce to a handful of universities.
- Wide-field spectroscopy is seen as a strength of the telescope. Conversely imaging is not seen as a strength.
- The telescope's longitude (and the fact it is in the south, like most major new facilities), combined with its ability to obtain time-baseline data on targets, is seen as a strength that is largely untapped.
- Ongoing support is needed for developing and maintaining software packages for processing data and maintaining archives (esp. for Large Programs).

We consider a number of scenarios. They do not cover all possible permutations, but they do cover options that were raised at the town hall meetings. Risks associated with each scenario are noted.

We first consider the time frame up until 2025. Over that period, Veloce and Hector will be integrated into operations. With the start of operations of 4MOST in 2023, one might anticipate a decline in demand for 2dF. However, 2dF will be more accessible. The first 5 years of 4MOST will be dedicated to surveys, and there will be no biannual call for proposals as there are with other ESO instruments.

Scenario #1: The status quo up until 2025: no new instruments, no refurbishments to existing instruments, and no changes to telescope operations.

Risks associated with this scenario are:

- 2dF becomes increasingly unreliable, leading to large amounts of telescope downtime and increased levels of dissatisfaction from the community due to the need to reschedule the telescope at short notice.
- 2dF's unreliability means that it is no longer usable for large programs or paid time proposals.
- Interest from the community declines and there is no willingness to provide funds to support operations beyond July 2022
- Interest from the international community in purchasing time also declines, leading to a shortfall in funds to operate the facility

Scenario #2: As in scenario #1, but with a refurbished 2dF and selling a larger fraction of time on the telescope to fund operations (recalling that at present around 10% is sold to external consortia).

Risks associated with this scenario are:

- Interest from universities to fund operations declines, as the time available for the funds they provide is decreased.
- 2dF is taken out of service for several months

Scenario #3: No new instruments, no refurbishments to existing instruments, decommission 2dF. Visitor instruments are still accepted. KOALA, Hector and Veloce available.

The number of instrument changes will not be significantly decreased (Hector uses a different top-end from Veloce+KOALA, Veloce and KOALA currently must be swapped between at the same focus), but fewer staff may be needed as the most complex and high-maintenance instrument (2dF) is removed. Operations costs would be expected to decrease by 20%.

Risks associated with this scenario are:

- Interest from the community declines as 2dF is no longer available, leading to difficulty generating operations funding beyond July 2022
- Interest from overseas collaborations for purchased time decreases (by at least half) without 2dF.

Scenario #4: A new instrument delivering the capabilities of the SOXS facility on NTT (or even a clone of that instrument) is built and commissioned for use by 2023. 2dF and KOALA decommissioned. SOXS, Hector, and Veloce are available for use and visitor instruments are still accepted. Time on the AAT (and potentially other facilities at SSO) is used as an in-kind contribution to an external facility, such as LSST. Selling time might be more attractive to external users.

The number of instrument changes will not be reduced, unless Veloce and SOXS can be fed from the 2dF top end. Operations costs come down by 20%.

Risks associated with this scenario

- Funding for a SOXS-like facility has not been identified. It is likely that it will be competing against projects seeking NCRIS or ARC funds to build instruments for larger facilities overseas.
- There is insufficient interest from the LSST consortium in the AAT+SOXS-like-facility capability.
- Interest from universities to fund operations declines, as there is less time available.

We now consider the time frame beyond 2025. The first four scenarios are also possible scenarios for the time frame beyond 2025; additional scenarios are as follows.

Scenario #5: The AAT ends its life as a scientific facility. This option received little support at the town hall meetings.

Risks associated with this scenario are:

- The AAT funds 50% of site costs for SSO, so closing the AAT is a real risk to the continued existence of SSO. Site costs for any other telescope remaining would need to be reduced, and/or licence fees paid by other tenants would need to increase.
- If Australia does not become a full member of ESO then the loss of the AAT would mean Australia loses essentially *all* current capacity to conduct front-line research in optical astronomy (at least until GMT becomes available).

Scenario #6 One or more new instruments are added to the telescope, while 2dF, HERMES and KOALA are decommissioned. Operations costs decrease by 20%.

Risks associated with this scenario are:

- Funding for a new instrument has not been identified. It is likely that it will be competing against projects that build instruments for larger facilities overseas.
- The time available for building a new instrument by July 2025 is short relative to the typical instrument construction time (at least 7 years from conception to operation).
- Interest from the community declines as 2dF is no longer available and there are no longer sufficient funds to fund operations beyond July 2025.
- Less interest from overseas collaborations purchasing time on the telescope due to the decommissioning of 2dF.