Decadal plan for Australian astronomy 2016–2025

Mid-term review

CAPABILITIES AND OPPORTUNITIES PAPER | JULY 2019

National Committee for Astronomy

A COMMITTEE OF THE AUSTRALIAN ACADEMY OF SCIENCE

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Mid-Term Review of the 2016-25 Astronomy Decadal Plan:

Capabilities and Opportunities paper

25 July 2019

National Committee for Astronomy
Australian Academy of Science

www.science.org.au/astronomy-midterm

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Background

The 2016–2025 Decadal Plan for Australian astronomy mapped out a vision for the development of current and new astronomical facilities. In preparation for the Mid-Term Review (MTR) of the Plan, due for publication in 2020, the National Committee for Astronomy (NCA) commissioned a summary of the current status of the Plan, noting areas of achievement, summarising current capability, and highlighting potential future opportunities that were not recognised at the time of writing of the Plan. This document is to serve as an initial guide to community discussions prior to drafting of the MTR document.

Terms of Reference

The Mid-Term Review of the Decadal plan for Australian astronomy: 2016–2025 will:

1. Review the main goals and priorities of the Decadal Plan and provide a succinct update on the state of Australian astronomy and significant changes since the completion of the Decadal Plan;
2. Review the recommendations of the Decadal Plan, reporting on the extent to which they have been accomplished, and whether recommendations remain appropriate or require revision; and
3. Review current plans for implementing the original or updated recommendations of the Decadal Plan, and provide revised implementation plans with priorities and contingencies, focussing on the period 2021–2025 but addressing the longer term where appropriate.

Process and Timeline

1. The NCA will appoint a CapOp Committee to inform the review process: Lister Staveley-Smith (NCA chair, ICRAR/UWA), Sarah Brough (UNSW), Amanda Karakas (Monash), Christoph Federrath (ANU), Eric Thrane (Monash).
2. The CapOp committee will summarise, update and combine the ten capability papers submitted to the NCA in December 2018 into a single *Capability and Opportunities* paper (this paper). The paper will be submitted to the NCA for review and approval prior to its meeting at the Astronomical Society of Australia (ASA) meeting at the University of Queensland in July 2019.
3. The NCA will appoint an MTR committee: Lister Staveley-Smith (NCA Chair 2019-2021; ICRAR/UWA), Tamara Davis (University of Queensland), Amanda Karakas (Monash University), Chris Tinney (University of New South Wales), Cathryn Trott (ICRAR/Curtin, President ASA). The MTR committee will oversee the process of receiving community input relevant to the MTR during the second half of 2019. The MTR Committee will be chaired by the NCA Chair and have broad representation across astronomical fields and institutions. The MTR chair will present a budget and a plan of community consultation by the July meeting of the ASA.
4. The MTR Committee will provide a first draft of the MTR for NCA and community review in early 2020.
5. The MTR Committee will complete the MTR and submit a final draft to the NCA by end May 2020.
6. The NCA will consider this draft at its July 2020 meeting and provide the final version of the MTR to the Australian Academy of Science's Executive Committee, the Australian Research Council and the astronomical community by end July 2020 for publication and launch by 30 October 2020.

Executive Summary

The 2016–25 Astronomy Decadal Plan advocated strategic investment in the areas of optical/infrared astronomy, radio astronomy, instrumentation programs, computational astronomy and astronomical data processing. Specifically, membership of the European Southern Observatory (ESO) and the Square Kilometre Array (SKA) Observatory was recommended. Further investment (at the 10% level) in the next-generation of 30-m class telescopes was also recommended.

Excellent progress in achieving many of the above goals has been achieved, with the standouts being a strategic partnership with ESO and membership of the SKA Observatory. There are compelling reasons to continue to advocate for the completion of the Plan's recommendations. In particular, the GMT project is healthy, although full membership of ESO should be considered as a viable alternative for access to further 30-m telescope time. New Australian instrumentation capability is now available due to the successful restructure of the AAO instrumentation group, and the completion of ASKAP. ESO and SKA membership offer opportunities for further development of instrumentation capability through design and construction contracts for the national observatories and university groups. Refreshed High-Performance Computing (HPC) facilities for observational and theoretical work has gone some way to redressing imbalance with overseas competitors.

However, several important new scientific directions that did not exist at the time of the Plan have become apparent. These include

- The new field of gravitational wave astrophysics, which follows the recent detection of black hole and neutron star coalescence events
- The potential to launch small space telescopes, and better international engagement in international space observatories following the creation of the Australian Space Agency
- New opportunities to create and federate data centres to better deal with vast observational data sets, and access powerful HPC facilities for large theoretical simulations beyond those originally envisaged in the Plan.

New sources of funding are likely to be available to assist with some of the above opportunities. However, the community needs to be prepared to rank these opportunities (and others not listed above) against each other, and against completion of remaining priorities in the Plan.

Review of Achievements 2016–2019

The 2016–25 Astronomy Decadal Plan identified the following equally-weighted infrastructure priorities:

A. Partnership equating to 30% of an 8-metre class optical/infrared telescope

B. 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

C. Partnership equating to 10% of a 30-metre class optical/infrared extremely large telescope (ELT), such as the Giant Magellan Telescope (GMT)

D. 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

E. 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.

The current status of these priorities is judged by the NCA to be:

A. **Achieved.** A strategic partnership with ESO was achieved in 2017. Australian access represents 30% of a single 8m telescope to the end of the strategic partnership in 2028.

B. **Achieved.** ASKAP is currently transitioning from its early science phase to full operations mode with all antennas. MWA Phase II commenced operations in 2017/18. Australia signed the SKA Observatory convention in March 2019.

C. **Partially achieved.** The future of the GMT project looks healthy, and access at the 6% level is assured through Australia's previous investment. Further capital investment (potentially in the form of the construction of instrumentation here in Australia) is required to raise that share to 10% when GMT goes into operation. Or Australia will have to invest in full ESO membership at the end of the current ESO strategic partnership to become a partner in the ELT.

D. **Partially achieved.** The restructuring of the AAO from an Executive Agency of DIIS, to the AAO Consortium (involving Macquarie University, Australian National University, University of Sydney and AAL) has resulted in new investment in instrumentation capability. Contracts between the AAO Consortium and both ESO and GMT are underway. The ATNF instrumentation program has now transitioned from ASKAP construction to other externally-funded projects including SKA pre-construction.

E. **Partially achieved.** Investments by AAL/NCRIS, CSIRO and DIIS in optical, gravitational wave and SKA data centres and data science capabilities have grown significantly over the first half of the Decadal Plan period. Funding for a refresh of the NCI and Pawsey facilities has been provided. However, the availability of HPC time remains well short of the level required for theory and simulation science to remain internationally competitive.

In addition to these infrastructure priorities, a number of community priorities were identified in the Decadal Plan:

F. Utilisation of astronomy to improve participation and the standard of science education in schools through teacher-training programs

G. Provision of graduate training that includes transferable skills to provide highly skilled graduates for roles in wider society

H. Establishment of a central body to promote and facilitate industry engagement with the next generation of global facilities

I. Adoption of principles and practices that aim for at least 33% female representation at all levels of Australian astronomy by 2025.

The current status is:

F. **Partially achieved.** Programs by CAASTRO, ASTRO 3D, OzGRAV, CSIRO and ICRAR are contributing to lifting science education standards in schools. Mission Gravity, for example, delivers astronomy education into the classroom and trains up teachers to deliver the material themselves.

G. **Partially achieved.** Well-funded internship programs and Centre of Excellence programs are contribution to graduate training, especially in the area of data science skills. More needs to be done to reach a wider graduate community.

H. **Not achieved.** Membership of ESO and the SKA has resulted in the appointment of industry bodies for the purpose of information sharing. The consolidation of optical (ESO) and radio (SKA) partnership/membership management within DIIS will increase the ability of these groups to interact with *Big Science.*

I. **Partially achieved.** Many institutes now have equity and diversity action plans which are aligned with this priority, with strong engagement with the SAGE/Athena Swan initiative to address gender imbalance. Some institutes have made (or committed) to female-only faculty hires.

Current Capabilities

Facilities

Funding for Australia's domestic national facilities (AAT and ATNF telescopes) has been continued, though at a reduced level in the case of the AAT. External funding for the AAT is growing, and Parkes is now substantially externally funded. These domestic facilities are essential in delivering unique research capability for major Australian-led research programs, providing platforms for the development of future instrumentation, and for providing local training for future generations of astronomers.

Australia's strategic partnership with ESO has been a major achievement of the last few years, and is delivering access to the four 8m telescopes of the VLT, plus all the other telescopes and facilities of the Paranal and La Silla Observatories to Australian astronomers. This cements community access to all telescopes on La Silla/Paranal for a period of 10 years and was an important priority in the Decadal Plan. Furthermore, it creates multiple opportunities for engagement by the national observatories and industry in contracts for the development and construction of future instrumentation and software.

ASKAP is now up and running with its full complement of 36 antennas, and several high-profile Nature and Science papers have already been published on Fast Radio Bursts and gas outflows. Pilot surveys commence this year. Meanwhile the Compact Array and Parkes telescopes continue to be operated at a reduced funding level, as indicated in the Decadal Plan. Their capabilities remain complementary to ASKAP and MeerKAT even after the latter becomes fully operational.

MWA phase 2 is operational, and analysis proceeds on higher-resolution continuum imaging of the sky, and further development of EOR detection techniques in preparation for the SKA.

Meanwhile, the SKA itself is unlikely to begin early science by the end of the current Plan period. The official commencement of *Key Science Projects* is now not due until 2029, which is a major delay compared to earlier timelines.

Similarly the GMT is making progress, but is reliant on a good ranking in the US *Decadal Survey* to ensure NSF funding required to complete construction and to provide a partial operations budget.

Participation in a number of other major facilities such as HESS, CTA, the enhanced Pierre Auger Observatory, IceCube, 4MOST, eROSITA and LSST has been facilitated by relatively small ARC or institutional contributions. However, sustaining even these small levels of contribution over multiple years is challenging.

Access to other major ground and space facilities such as ALMA and HST continues through generous open-skies policies, a policy which is reciprocated by Australia's national facilities.

The HPC national facilities at NCI and Pawsey have both been upgraded at a level which helps them maintain, but not increase, their competitiveness. But both upgrades are very welcome and are timely for the radio and theory communities in particular.

Community

The arrival of the ASTRO 3D Centre of Excellence as a replacement for CAASTRO, and the funding of a brand new Centre for Gravitational Wave Discovery, OzGrav, has further strengthened the astronomy research community since the publication of the Decadal Plan. These Centres (combined funding $80M) are not only long-term (7-year) investments in astronomy research capability, but are important triggers for even longer-term university investments in tenured staff. The funding of these Centres represents recognition by the ARC of the good performance by the Australian astronomy community, itself has been facilitated by continued good access to world-class facilities.

The research output of Australian astronomers has also consistently lifted over the last few years, which is against the trend in other areas of the *Physical Sciences*. The number of refereed astronomy papers published in high-impact factor journals increased by a factor of 2.5 from 2008 to 2018. The level of collaboration also increased, with the percentage of papers involving two or more Australian institutes increasing from 24% to 50%.

The 2016-25 Plan was titled *Australia in the era of global astronomy*. The funding of ASTRO 3D and OzGrav and the signing of the SKA convention and ESO strategic partnership have cemented our global astronomy collaboration at the highest level. The number of unique refereed research papers with international co-authors has doubled every 4 years over the last two decades.

Engagement with the broader community has also been facilitated by increased investment by the large centres, namely ICRAR, ASTRO 3D, OzGrav and CSIRO.

Optical/Near-Infrared Landscape

Towards full ESO membership

Australia's strategic partnership with ESO is a significant achievement since the publication of the Decadal Plan. This partnership provides Australia's optical/infrared astronomy community with the requested ~30% of an 8m telescope via a 10-year agreement from June 2018. The 4x8m Very Large Telescope (VLT) provides extensive instrumentation including optical and near-IR imagers, spectrographs and integral field spectrographs. As well as the VLT the strategic partnership also provides access to all the telescopes of ESO's La Silla-Paranal Observatory (VISTA 4m survey telescope with near-IR imager; VLT survey telescope, with optical imager; ESO 3.6m with the HARPS dedicated planet searcher, 3.5m New Technology Telescope with IR spectro-imager and optical multi-mode instrument).

Australia needs to consider converting its current ESO strategic partnership to full ESO membership well before the end of this Decadal Plan's period, or seek large telescope access elsewhere. Full ESO membership would deliver access to its 39m ELT, the Paranal and La Silla observatories and the sub-mm ALMA array. The cost threshold for full ESO membership is substantial, and while that funding would formally fall within the next Decadal Plan period, funding to join ESO would need to be committed before the end of this Decadal Plan's period.

Towards full GMT Membership

Australia has invested in the next-generation 24.5m Giant Magellan Telescope (GMT; in which the combined AAL and ANU shares represent ~6%). GMT's first-generation instrument suite includes a multi-object spectrograph, an optical echelle spectrograph (the only one planned for the first generation of any 30-m class telescope), a high-resolution NIR spectrograph (GMTNIRS), a near-IR adaptive-optics-fed imager and integral field spectrograph (GMTIFS) and the MANIFEST facility fibre system (the latter two being built in Australia).

GMT will be the first 30-m class telescope to go into operation, and is working towards full funding with the US NSF willing to contribute US$700-800m if the GMT is highly ranked in the current US astronomy Decadal Survey. Further investment over the next five years (potentially via instrumentation construction here in Australia) would be required to raise our current 6% share, to our 10% target, when GMT goes into operation.

Local Capabilities

Ground-based optical and infrared instrumentation is now supported by the Australian Astronomical Optics (AAO) national capability, which currently has nodes at AAO-Macquarie, AAO-Stromlo and AAO-Sydney. For the ten years of the ESO strategic partnership it is expected that there will be $5M/year in NCRIS funding for optical/infrared instrumentation, primarily to maximise Australia's global scientific engagement, notably with ESO and GMT. The Australian-led MAVIS (MCAO-Assisted Visible Imager

& Spectrograph) instrument for ESO's VLT is an excellent example of this. MAVIS was selected from a competitive call for instruments and if successful in its current 15-month Phase A study, would be on-sky in 2025.

Similarly, the Anglo-Australian Telescope (AAT) is only funded from July 2018 - June 2022. The AAT could potentially continue to serve the community for many years as a survey telescope, a technology testbed, a potential in-kind contribution and as a training facility.

Australia’s current high level of access to optical/infrared facilities could easily be severely eroded over the next decade.

Issues

The MTR should consider

1. How should we achieve full ESO membership?
2. How should we achieve 10% GMT membership?
3. What is the long-term strategy for the AAT?
4. What are the strategies and priorities for the potential future scenarios, which range from not gaining full ESO membership and GMT not being built, to obtaining full-membership of ESO as well as 10% access to GMT?
5. In what ways can the community develop instrumentation capability that optimises scientific return on telescope investments, including increased interaction with industry?
6. How should we prioritise the new (and any other) potential capabilities and develop plans for engaging with these projects?

Radio Landscape

Local Capabilities

The major current radio astronomy facilities in Australia are ASKAP, ATCA and Parkes, which are run by CSIRO, and MWA, UTMOST and the UTAS facilities, which are run by University-led consortia. Other domestic facilities that are available at a reduced level include a VLBI/AuScope network and the Mopra and Tidbinbilla facilities. Underpinning these facilities is an extraordinary national instrumentation, engineering and 'backend' capability developed over many years, and recently strengthened by deep involvement by a number of groups in the SKA and its precursors.

Towards the SKA

As foreseen in the Decadal Plan, major new opportunities for the remainder of the 2016-2025 decade revolve around ASKAP, MWA and the SKA. The main surveys with full ASKAP are expected to be fully operational in 2020, so this facility be massively productive for the remainder of the Decadal period and beyond. Similarly, MWA upgrades will be useful in improving EOR limits, exploring the low-surface-brightness continuum sky, and further developing analysis and calibration methods. Scientific productivity will be strengthened by early involvement in *SKA Regional Centres*. The transition to SKA science is no longer likely to start happening at the end of the 2016-2025 decade as envisaged in the Decadal Plan. The community should consider how to exploit this gap to increase the scientific exploitation of the pathfinders, and better position the Australian astronomers for SKA science leadership. There also remains room for better exploitation of the incredibly radio-quiet MRO site. The tentative 'cosmic dawn' detection by EDGES is a prime example of what is possible.

Future Opportunities

Data Centres and High Performance Computing

Current Capabilities

In the Australian scientific landscape there are three main centres that provide hardware for High Performance Computing (HPC) and the storage of large volumes of data. The three sites include:

1. National Computational Infrastructure (NCI): Provides HPC and data services for a broad range of clients including university partners, Australian Research Council (ARC) Centres of Excellence, and government agencies (e.g., CSIRO). HPC usage at NCI is divided up accordingly, with the National Computational Merit Allocation Scheme (NCMAS) accounting for 19% of the share of NCI supercomputer time.
2. Pawsey Supercomputing Centre: Provides HPC and data services. Supercomputer time is allocated in a similar way to NCI with roughly 25% going to NCMAS and at least 25% dedicated to radio astronomy. Current NCI and Pawsey machines provide of the order of 2.7 Pflops/s[1] when combined, about 100 times less than the top supercomputers in the world.
3. Swinburne Centre for Astrophysics & Supercomputing: Swinburne's main distinction has been the hybrid nature of the supercomputer, with a mix of GPU and CPU available. AAL also support personnel and guarantees that 20% of the available supercomputer time goes to Australian astronomers. Roughly 70% of supercomputer time at Swinburne goes toward astronomy-related activities. The ARC funded Centre of Excellence OzGrav currently has 35% of OzSTAR dedicated usage.

[1] https://www.top500.org/lists/2019/06/

While we separate out HPC for theoretical simulations and HPC and data storage for astronomical observations, both of these areas benefit together from government spending.

Data Centres and Astronomy Data Archives

Astronomical observations and theory can produce significant quantities of data. The issue of long-term safe storage requires significant investments in data storage facilities and the people to run them. Furthermore, data from radio and optical telescopes and gravitational wave detectors often requires further analysis and processing before storage, hence the need for Data Centres, which can do both. These Centres are often - but not always - linked with HPC centres such as NCI and Pawsey.

CSIRO Astronomy and Space Science (CASS) provides access to radio astronomy data through several data archives including the Australia Telescope Online Archive, Parkes Pulsar Data Archive and CSIRO ASKAP Science Data Archive.

Some astronomy data archives are linked by the All-Sky Virtual Observatory (ASVO) including AAO Data Central, hosted by Macquarie University, the SkyMapper Archive, hosted by NCI, the Murchison Widefield Array Archive, hosted by Pawsey, and the Theoretical Astrophysical Observatory, hosted by Swinburne. CSIRO ASKAP Science Data Archive is also accessible via ASVO.

High Performance Computing

HPC facilities are required for the (post)-processing of astronomical data (the role of Data Centres) and for enabling theoretical simulations (requiring access to highly scalable systems). The requirements for post-processing of data and large astrophysical simulations are quite distinct. For example, storage and post-processing of observational data can often be achieved on compute nodes that are not tightly coupled, whereas most large-scale theoretical simulations require nodes that have fast interconnect and provide scalability to thousands of compute cores.

The pathways for funding HPC for astronomical data processing and for theoretical simulations are also different, with funding for hardware infrastructure built into the telescope design. The Galaxy supercomputer at Pawsey, for example, is dedicated to the operational requirements of the SKA pathfinder telescopes, ASKAP and MWA.

HPC time for theoretical simulations is primarily awarded through NCMAS although some universities (e.g., ANU, Swinburne) have dedicated time through partner shares or in-kind investments. The ARC Centre of Excellence ASTRO 3D partners with NCI, which provides dedicated HPC time for ASTRO 3D investigators, while OzGrav members have dedicated access to the OzSTAR supercomputer at Swinburne. These special arrangements provide of order 10 million compute hours per year and only to these specific centres.

Successes

Successes in the HPC and data landscape include the establishment of the Astronomy Data and Computing Services (ADACS) and the establishment in 2019 of an Australian Gravitational Wave Data Centre. ADACS was established in early 2017 by AAL to provide training, data and software development as well as training to the national astronomy community and is currently funded to mid-2002.

Opportunities and issues

There are a number of looming issues including:

1. **Support and training**: Funding provided by AAL for ADACS has occurred on a financial year-by-year basis. The current funding model does not allow for long-term planning or retention of skilled personnel. A well resourced and sustainable ADACS would help provide crucial expertise to the observational and theory communities alike.
2. **HPC access**: A consistent message from the Australian theory community is the need for access to a world-class HPC facility. Computational astrophysics groups in Australia have access to < 1/3 of the HPC resources available to similar groups in Canada, which has a similar population and GDP. Currently, ~25% of Australian large-scale HPC users are able to access top international supercomputers in order to meet their computational needs.
3. **Data storage and management:** Data from current and next generation radio telescopes pose particular problems with regards to data management (e.g. the processing of large data cubes) and long-term storage. This issue is only going to be exacerbated with increasingly large volumes of data from new radio facilities.

Next-generation capabilities

The Gravitational Wave Data Centre may provide a model for other Data Centres around the country (e.g., an Optical Data Centre combining optical data from Australian facilities with ESO data). Indeed, further work with ASVO nodes (CASDA, AAO Data Central, Skymapper, MWA and TAO) will allow Australian astronomers to more easily exploit the data and maximise the science from Australian facilities.

An international network of SKA Regional Centres has been proposed which will enable the community to exploit the SKA data for science. Planning for the Australian SKA Regional Centre is already underway, led by ICRAR and CSIRO. A prototype Centre would be beneficial for the community through opportunities for advanced scientific analysis of data from the SKA pathfinders.

There may be an opportunity to build strategic partnerships with Pawsey, NCI and OzSTAR to enable more HPC resources for astronomy. Pawsey and NCI have received approximately $70M each from the Australian Federal government to refresh HPC infrastructure. Other options include the purchase of compute time on domestic or overseas facilities.

Gravitational-wave astronomy: capabilities & opportunities

The birth of a new field

The past four years have seen a scientific revolution through the birth of a new field: gravitational-wave astronomy. The first detection of gravitational waves (GW150914) — recognised by the 2017 Nobel Prize in Physics—provided unprecedented tests of general relativity while unveiling a previously unknown class of massive black holes, thirty times more massive than the Sun. The subsequent detection of gravitational waves from a merging binary neutron star (GW170817) confirmed the hypothesised connection between binary neutron stars and short gamma ray bursts while providing an independent measurement of the expansion of the Universe. The discovery enabled precision measurement of the speed of gravity while shedding light on the origin of heavy elements. At the time of writing, the Laser Interferometer Gravitational-wave Observatory (LIGO) and its European partner, Virgo, have announced the detection of more than twenty gravitational-wave events. This fast-growing transient catalogue is expected to yield insights into a number of topics, from the equation of state of matter at supra-nuclear densities to the fate of massive stars.

Current capabilities

1. Australia's eminence in the global gravitational-wave community has been facilitated through a series of LIEF grants, establishing *partnership* status in the LIGO Scientific Collaboration. This funding enables Australian contributions to the upgrade of the LIGO facilities. It also covers the cost of membership, enabling Australian researchers to lead analysis of LIGO data.
2. The construction of the OzSTAR computing cluster, 30% of which is devoted to gravitational-wave astronomy, has provided computational resources for ambitious new projects.
3. The new $2M NCRIS Gravitational Wave Data Centre leverages the OzSTAR cluster by providing the personnel necessary to maintain software and database systems required to host and process large volumes of gravitational-wave data.
4. Australian gravitational-wave astronomy is strengthened by leadership in pulsar timing, which seeks to detect gravitational waves at nanohertz frequencies. Our current capabilities in the area include strong programs at the Parkes Observatory and MeerKAT telescopes that have strong synergies with LIGO.

Opportunities and priorities

1. As the current generation of gravitational-wave observatories drive a revolution in astronomy, the global community is looking forward to "third-generation" (3G) observatories. The science potential of 3G observatories is enormous, enabling measurements of gravitational waves from the edge of the Universe and precise determination of the neutron star equation of state. Australia is well-positioned to develop the technology required for the measurement of high-frequency gravitational waves needed to yield insights into the nature of nuclear matter at extreme densities. The Mid-Term review should consider investment in an Australian Gravitational-Wave

Pathfinder that develops and validates core technologies required for the global 3G detector network. This pathfinder will put Australia in a position to host a major facility while creating the technology necessary for the global 3G network.

2. The midterm review should consider prioritising support for the Gravitational Wave Data Centre above the current funding levels through 2026, including the establishment of a LIGO Tier-2 data centre. This support will enable Australia to consolidate the increased influence gained since the detection of gravitational waves, while growing capacity for gravitational-wave analysis of data with radio telescopes such as the SKA.

Space

The Australian Space Agency

The establishment of an Australian Space Agency on 1 July 2018 represents an enormous change in government strategy since the publication of the Decadal Plan. As noted in the Plan, space-based facilities accounted for 30% of all citation-weighted publications in the field of optical/IR astronomy. Future facilities such as JWST and WFIRST which target exoplanets, early stars and distant galaxies are likely to further add to this activity.

The astronomy community has since played a facilitation role in helping ESA prioritise the construction of a second deep-space tracking station at New Norcia, and CSIRO has recently taken over the management of this facility from Inmarsat, complementing their management of the Tidbinbilla station. The possibility of low-cost, high-value partnerships which allow access to future instruments such as WFIRST via radio and IR downlinks could be considered by the MTR.

The Australian Space Agency has also expressed interest in supporting low-cost cubesats which offer clever ways to undertake unique science in niche research areas, such as measuring radiation from the warm-hot intergalactic medium. Instrumentation facilities such as those at ANU and UNSW can contribute to the design, manufacture and test of small instruments and spacecraft

Furthermore, with the advent of cubesats and the increasing danger from space debris, the issue of crowding and space situational awareness becomes ever more important. Passive optical and radio tracking may play an important role in this area, possibly leading to other sources of funding for the operation of astronomical facilities such as the MWA.

Opportunities

In considering new opportunities in this area, the MTR should

- Explore ways in which the advent of the Australian Space Agency could help Australian astronomers to gain better access to optical/infrared facilities in space (e.g. WFIRST) through provision of ground support facilities, including download (deep space and cubesat) and signal pre-processing.

- Consider development of leapfrog infrared laser technologies for high bit-rate space-to-ground communication.
- Consider proposing significant partnerships between the Australian Space Agency and NASA or ESA to build instruments for future missions.
- Explore partnerships between ESA/NASA based on rapid processing of downloaded data from space missions - e.g. the rapid generation of transient alerts.

Other Opportunities

There are further major opportunities for Australian astronomy to add new capabilities which need to be considered in the MTR process. Some of these have progressed significantly since the last Decadal Plan:

- National access to LSST, the ‘apex’ optical imaging facility over the next few decades.
- Access to an 8-12m-class spectroscopic survey facility (e.g. Mauna Kea Spectroscopic Explorer [MSE]) or similar telescope being considered by ESO post-ELT.
- Access to a 2-4m class wide-field optical/infrared telescope in Antarctica, such as the Australian PILOT concept or the Chinese KDUST facility.
- Access to NASA’s 2.4m WFIRST mission, providing deep and wide-field optical and near-infrared imaging at high spatial resolution, wide-field grism spectroscopy, integral field spectroscopy, and a coronagraph for exoplanet imaging & spectroscopy.
- Access to ESA’s 1.2m Euclid satellite, which has a high quality panoramic visible imager, and a near infrared photometer and slitless spectrograph.
- Assuming successful mission verification, building on the AAL MoU with the German eROSITA consortium to better engage in all-sky multiwavelength X-ray/radio/optical projects.
- Access to the H.E.S.S. data at TeV gamma ray energies for transients, variable sources and continuum studies. Current membership expires in 2020.
- Access to the next generation TeV Cherenkov Telescope Array (CTA). CTA science is intimately linked to many aspects of SKA science and that of optical astronomy (non-thermal physics, transients, dark matter). Long term (>5-10 yr) CTAO membership should be considered by the community.
- Major upgrades to the Pierre Auger Observatory (better discrimination of elemental species) and IceCube (improved angular resolution and energy threshold) present new opportunities to tie in with major Australian investments in radio and optical astronomy, now that these two new areas of astronomy are finally established.

Finally, the issue of how to manage access and engagement with mid-tier facilities, such as some of the above, needs to be considered by the MTR. The AAL is not set up as a national observatory, so is already stretched in its technical and operational capability to manage even existing facilities. If prioritised by the community, how should national engagement with LSST be managed for example? If a more national approach to coordination of HPC and data centres is recommended, how should this be managed?

Appendix A: Reference documents

- 2016-25 Decadal Plan: www.science.org.au/supporting-science/science-sector-analysis/reports-and-publications/decadal-plan-australian
- Capabilities and Opportunities briefing documents:
  - ALMA/THz astronomy (Claudia Lagos)
  - Data centres (Minh Huynh)
  - Education and outreach (Fred Watson)
  - Gravitational waves (OzGrav)
  - High energy astronomy (Gavin Rowell)
  - Optical/infrared astronomy (Matthew Colless)
  - Radio astronomy (Lister Staveley-Smith and Douglas Bock)
  - Social and cultural (Rachel Webster)
  - Space (Sarah Pearce)
  - Theory (Chris Power)