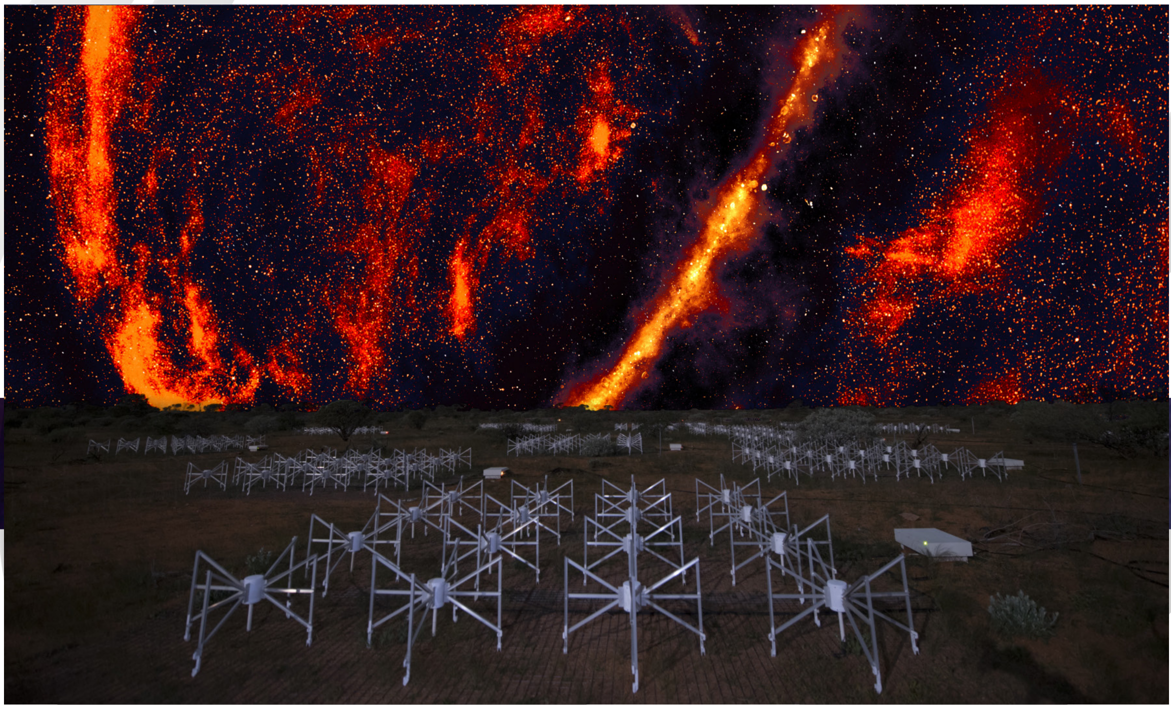
Astronomy Australia Ltd.

2015 / 16
Annual Report



Astronomy Australia Limited

Vision

Australian-based astronomers will have access to the best astronomical research infrastructure.

Mission

AAL will achieve its vision by engaging with astronomers in support of the national research infrastructure priorities of the Australian astronomy Decadal Plan, and advising the Australian Government on the investments necessary to realise those priorities.

Principles

1. Access to major astronomical research infrastructure should be available to any Australian-based astronomer purely on scientific merit.
2. The concept of national astronomical research infrastructure includes participation in international facilities.
3. AAL recognises the roles of other organisations in Australia that manage components of the national astronomical research infrastructure.

Who we are

Astronomy Australia Limited (AAL) is a not-for-profit company whose members are all the Australian universities and research organisations with a significant astronomical research capability. AAL works with Australia's National Observatories, relevant infrastructure providers, astronomers at Australian Universities, and the Australian Government to advance the infrastructure goals in the Australian Astronomy Decadal Plan 2016-2025, Australia in the era of global astronomy.

What we do

Since its incorporation in 2007, AAL has coordinated the Australian astronomy response to, and managed the funding for, a number of national schemes and projects, including the Australian Government's investments in astronomy infrastructure through the National Collaborative Research Infrastructure Strategy (NCRIS). AAL-administered funding has enabled construction, instrumentation development, upgrades, maintenance and operations across a portfolio of world-class astronomy facilities and projects. In this era of global astronomy, AAL also plays a key role representing Australia's interests in a number of major international projects and partnerships.

Our Values

AAL is committed to equity and diversity and endeavours to create an environment in which every individual is treated with dignity and respect.

Image: The winning image NGC3310 from the 2015 Gemini School Astronomy Contest, organised by the Australian Gemini Office.
Image Credit: AAO ITSO Office

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Front cover image: **Radio sky above the MWA.**
Image credit: **CAASTRO, Museum Victoria, MWA GLEAM Team, Alex Cherney**

A message from the Chair

It has been another exciting and fulfilling year for AAL and the Australian astronomy community, with a significant highlight being the official launch of the 2016-2025 Australian Astronomy Decadal Plan at Parliament House by the Hon. Karen Andrews MP in August 2015. The Decadal Plan articulates the community's shared vision for how Australia can continue making significant contributions to science, innovation, and education. AAL now looks forward to playing a key role in advancing the goals of the new Decadal Plan. In particular, AAL is contributing to the Australian Government's National Research infrastructure Roadmapping exercise to outline the future infrastructure requirements that will enable the next astrophysical breakthroughs and discoveries.

Diversity and inclusiveness in the workforce are important ingredients that help boost performance, productivity and innovation. One of AAL's significant achievements in 2014 was to receive a Bronze Pleiades Award from the Astronomical Society of Australia in recognition of our commitment to gender equity and flexible working arrangements. In 2015/16, we continued to advance the goals we set out in our statement of values, and had a number of notable achievements, including a majority of female Directors on the Board and the first female Chair of the Board.

To ensure that AAL has the information and skills necessary to appropriately advance the infrastructure priorities in the new Decadal Plan, in late 2015 AAL established two new working groups: 1) the Multi-Messenger Astronomy Working Group to advise AAL on investments opportunities in gravitational wave, cosmic ray, gamma ray, neutrino and gravitational wave facilities, and other complementary areas of astronomy; and 2) the Computing Infrastructure Planning Working Group to advise on investments in computing and data infrastructure, skills and training in order to address the science goals in the Decadal Plan. In addition, at the November 2015 Annual General Meeting (AGM), the AAL members voted to modify the AAL constitution to broaden the scope of expertise and experience required on the AAL Board, in order to reflect the breadth of research infrastructure recommended in the current Decadal Plan.

I would like to comment on some of our project successes during the year. It is very pleasing that a quarter of approximately 3000 users of facilities are students and that usage of AAL-funded facilities is more than 200% oversubscribed. In addition, there have been many science results announced that have enhanced Australia's reputation as a leader in astronomy across the world, several of which are described under Science Highlights.

The billion-dollar Giant Magellan Telescope (GMT) project, in which Australia is a 10% partner, reached an important milestone with the commencement of the construction phase in November 2015. This was triggered by the 11 international founders committing over US$500M towards the project, and keeps the project on track to begin operations in early 2021 as the world's first 25-metreclass telescope. I was delighted to be able to represent AAL at the "ground-breaking" ceremony on the site in Chile, in November 2015, along with Matthew Colless, ANU *(image right).* AAL continues to play an important role on the GMTO Board and its committees.

Australia's NCRIS-supported Square Kilometre Array precursors were two of the first telescopes in the world to make rapid follow-up observations of the first-ever gravitational wave detection (detected in Sep 2015 and announced in Feb 2016). The gravitational wave detection is one of the most significant scientific discoveries of the last century. Astronomy-NCRIS facilities will continue to exploit their unique capabilities (including wide-field of view, fast survey speed, high resolution and sensitivity, and southern hemisphere location) to play an exciting role in the emerging field of gravitational wave astronomy.

I would like to take this opportunity to personally thank three AAL Directors who retired from the Board at the November 2015 AGM. The retiring Chair Brian Schmidt and Directors Brian Boyle and Robyn Owens have made tremendous contributions to the work of AAL, and it has been a great pleasure working with them. In particular, Brian Schmidt has been a Director since the incorporation of AAL in 2007 and retired as Chair to take up a position as Vice Chancellor of ANU. He has had an amazing influence and impact to benefit astronomy and science in general.

At the 2015 AGM, AAL welcomed three new Directors, Rosalind Dubs, Matthew Bailes and Rachel Webster. Ros is a distinguished Company Director and brings much expertise from the corporate sector. She was elected Deputy Chair by the Directors, a role she has filled with distinction. Rachel and Matthew are both esteemed astronomers with national and international reputations and they bring comprehensive expertise in wide-ranging science, academic management and technical experience.

Image: **GMT Ground breaking ceremony**
Image Credit: **GMTO Corporation**

Also at the AGM, I was honoured to be appointed as Chair of the Board and I have done my best to discharge the duties effectively over the past year. My term as Director ends in 2016 and after six years on the Board I believe it is time to step down. It has been an enormous privilege to be part of this exciting organisation that has been an effective champion for astronomy research and the infrastructure needed to achieve the excellent science and technical outcomes described in this report. My sincere thanks to Mark McAuley, the CEO, and all the staff of AAL for their unstinting support and dedication. To the Members, Directors and staff of AAL my very best wishes and thanks for the opportunity to be a part of this collegial and enthusiastic organisation. I am optimistic that AAL will continue to play an important role in providing access to the best research infrastructure for the Australian astronomical community.

Professor Anne Green, Chair

A message from the CEO

The announcement of the Australian Government's National Innovation and Science Agenda was a significant development in 2015/16. Major research infrastructure projects require long-term financial commitments and the National Innovation and Science Agenda includes $1.5 billion to enable NCRIS to continue at its current level for the next ten years, along with $293.7 million to meet Australia's commitments to the Square Kilometre Array (SKA) during that period. The policy also highlighted the Australian Government's expectation that investments in research infrastructure are part of a broader innovation agenda that includes industry and other direct benefits to Australia. Astronomers will have the opportunity to both benefit from this Australian Government initiative and support the related industry objectives.

This long-term NCRIS allocation was accompanied by the establishment of an expert working group, chaired by the Chief Scientist, Dr Alan Finkel to produce a research infrastructure roadmap for the next ten years. AAL and the National Committee for Astronomy are collaborating to provide input to the Chief Scientist concerning the research infrastructure opportunities associated with the Decadal Plan. The roadmap is expected to be finished around December 2016.

In March the Department of Education and Training announced the allocation of the NCRIS grants for 2016/17. All twenty-seven NCRIS capabilities were awarded their 2015/16 NCRIS grant plus two percent. For AAL this translates to $8.817 million. AAL also received $1.5 million of new funding from the Department of Industry, Innovation and Science to support access to 8m-class telescopes. These two major grants, along with a $0.225 million eResearch grant, total $10.542 million secured for astronomy during the 2015/16 financial year.

While the dollar amount, award-date and terms of the individual grants secured by AAL in recent years has varied considerably, the total dollars secured continues to be stable at ten or eleven million dollars per year.

To guide the allocation of expenditure during 2016/17 and beyond, the AAL Board released its funding priorities in May 2016. Those funding priorities seek to advance the research infrastructure priorities of the Decadal Plan in the context that AAL-managed grants are just one channel through which the Australian Government supports astronomy research infrastructure. AAL's funding priorities include access to large optical telescopes and the growing computing demands of modern astronomy, along with various university-led projects consistent with the Decadal Plan. While AAL does not currently manage grants directly associated with the SKA or Giant Magellan Telescope (GMT), AAL will continue to pro-actively support Australian involvement in those major projects.

AAL staff and directors were delighted to visit our member organisations during 2016 to brief them on AAL-supported achievements and developments, and to seek feedback to inform our planning for future investments. AAL endeavours to represent the interests of all Australian-based astronomers, and therefore in 2015/16 we were delighted to welcome our newest AAL member organisation, the University of Southern Queensland. There are now sixteen AAL member organisations and their activities are reflected in the excellent science and technical outcomes described throughout this report.

Advances in astronomy are so often enabled by technology innovation. The team behind CSIRO's ASKAP telescope are to be congratulated for receiving CSIRO's highest honour, the Chairman's Medal. This award was announced in October and recognises exceptional teams that have made significant scientific or technological advances of national, international and/or commercial importance. The citation for the award reads, "For revolutionising astronomy by developing a spectacular new capability for observing wide areas of the sky using the world's first widefield imaging receivers for radio astronomy on the antennas of the ASKAP radio telescope."

The combination of long-term funding and technology innovation are critical to the success of astronomical research infrastructure. Of equal importance is a robust governance platform to effectively convert those dollars and ideas into world-leading facilities to enable astronomers to undertake great science. In recognition that Australian astronomy exists in the era of global astronomy involving international billion-dollar projects, the Department of Industry, Innovation and Science has reviewed the governance arrangements for national astronomical research infrastructure. AAL has been deeply involved in that process and supports the objective of establishing a more consolidated governance model that is appropriately funded to realise the research infrastructure priorities of the Decadal Plan. I believe AAL has effectively explained the funding and governance arrangements required by Australian astronomy and the benefits that will flow from those arrangements. I eagerly await the long-term arrangements that the Australian Government will implement to allow astronomers to continue to contribute to Australia from a position of research excellence.

Mr Mark McAuley, Chief Executive Officer

Image: **AAL CEO, Mark McAuley at ANU's 2.3m telescope, Sliding Spring Observatory**

2015/16 Snapshot

$10.6M invested — *Infrastructure funding*

AAL invested $10.6M in 2015/16, giving Australian researchers access to facilities worth over $500M.

313 publications — *Scientifically productive*

AAL-supported facilities continue to be very scientifically productive with continued growth in the number of refereed journal papers published in 2015/16 from collaborative research projects.

88% collaborating internationally — *Inspiring collaborations*

Australian astronomers are exceptionally collaborative, with 88% of the publications in 2015/16 from AAL-supported facilities involving Australian-international collaborations. This is an important factor driving Australia's high level of research impact and productivity in astronomy.

25% student usage — *Commitment to training*

A quarter of Australian users of AAL supported facilities in 2015/16 were students, increasing in absolute numbers from 570 in 2014/15 to over 720. This demonstrates the value of this infrastructure in developing the skills and expertise of the next-generation of world-leading scientists.

users >2900 — *Demand for facilities*

Over 2900 astronomers used AAL funded facilities in 2015/16, of whom 54% were Australian-based researchers and 46% were international collaborators. This is almost twice as many users in 2014/15 and is evidence of the growing demand for these exceptional facilities.

203% subscription — *Highly competitive*

Access to AAL-supported facilities is highly sought-after and competitive, with users applying for twice as much time as was available in 2015/16, via merit-based time allocation processes.

Image: **Site for the GMT which will be located at the Las Campanas Observatory in Chile's Atacama Desert.** Image credit: **GMTO Corporation**

A full list of scientific publications in refereed journal articles that made use of AAL-supported facilities in 2015/16 can be found on the AAL website at: www.astronomyaustralia.org.au/publications

The Year in Highlights

Image: **MkII PAF installed on ASKAP**
Image Credit: **CSIRO**

The Year in Highlights:
Science

2015/16 has seen many outstanding science outcomes and discoveries resulting from work undertaken by Australian researchers using NCRIS-supported astronomical infrastructure. We highlight here just a few examples of research breakthroughs that build upon Australian excellence in astronomy research and technology, and which will further enhance Australia's reputation as a leader in astronomy across the world.

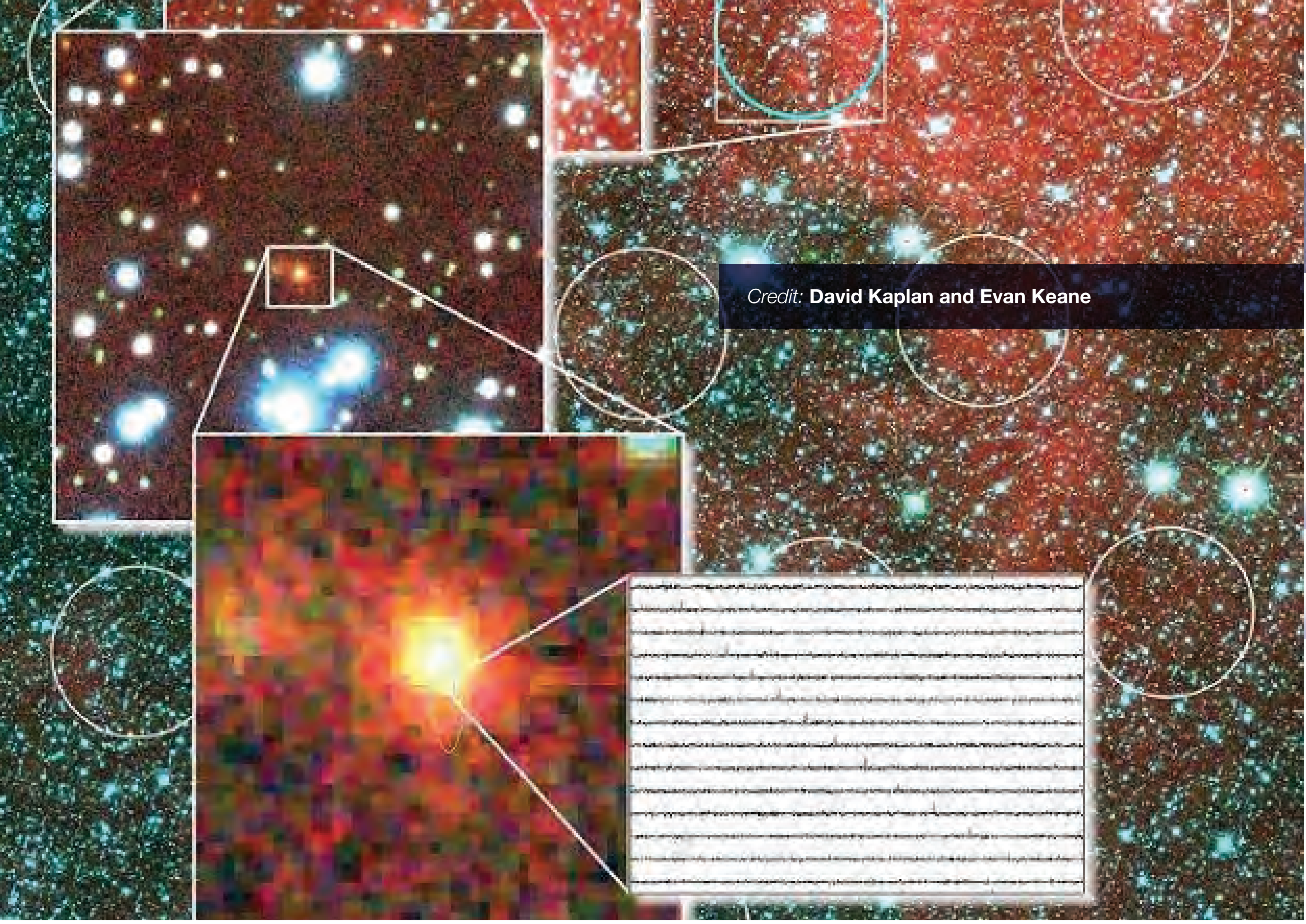
Australian telescopes join the hunt for the source of the first detected gravitational wave

One of the most significant scientific discoveries of recent times was announced in February 2016 with the first ever direct detection of gravitational waves by the international Laser Interferometer Gravitational-Wave Observatory (LIGO) and Virgo consortium. These ripples in space time, caused by a violent cosmic event in the distant Universe, had been predicted by Albert Einstein 100 years ago but never before observed. They open up an entirely new window on the Universe, akin to being able to hear as well as see the cosmos.

In addition to Australian researchers playing a scientific and technical role in the LIGO project, two NCRIS-funded Australian telescopes played an exciting part in taking rapid follow-up observations of the detection. The two Australian SKA precursors, the Australian SKA Pathfinder (ASKAP) and the Murchison Widefield Array (MWA), exploited their unique combinations of wide field of view, high sensitivity and rapid response times, to quickly mobilise and begin the hunt for the source of the detection. MWA is especially agile, as it has no moving parts and can observe the right part of the sky moments after receiving a trigger to follow up transient astronomical events. Australian facilities including MWA, ASKAP and the SkyMapper optical telescope, will continue to play key roles combining their follow-up observations with data from observatories around the world as part of a coordinated global effort to understand the nature of these events.

In this case, MWA and ASKAP did not detect a radio frequency counterpart, as the event appeared to be the result of a merger of two black holes, which is not predicted to create a detectable electromagnetic signal. LIGO scientists estimate that the black hole merger happened about 1.3 billion years ago, converting energy equivalent to 3 times the mass of our sun into gravitational waves, with a peak power output about 50 times that of the whole visible universe.

Image credit: The SXS (Simulating eXtreme Spacetimes) Project



Credit: **David Kaplan and Evan Keane**

Solving the mystery of fast radio bursts

Fast radio bursts (FRB) are short but intense explosions that release the same amount of energy in a single millisecond that the sun produces in 10,000 years. In 2014, an Australian-led team were the first to capture an FRB using CSIRO's Parkes radio telescope in New South Wales. Since then, scientists have puzzled over FRBs: where do they come from and what causes them? To help solve this mystery, Australia is leading the most comprehensive effort currently underway, the Survey for Pulsars and Extragalactic Radio Bursts (SUPERB).

In February 2016, the SUPERB team announced in the journal Nature that it had identified for the first time the galaxy hosting an FRB; an elliptical galaxy about six billion light years away. This breakthrough made use of follow up observations with CSIRO's Australia Telescope Compact Array (ATCA) radio telescope to pinpoint the object with high precision and the Subaru optical telescope to determine the galaxy type and distance. FRBs are also a new tool for weighing the Universe because the radio signal exhibits frequency-dependent delays imparted by the matter it has passed through. This allowed SUPERB to measure the amount of matter in the universe.

SUPERB aims to detect many new FRBs, swelling the known population and providing a more detailed picture of this phenomena. To do this, the SUPERB survey maintains strong links with a large number of international observatories. Upon detection of an FRB within SUPERB, alerts are sent to a range of collaborating observatories with the aim of tracking down the host galaxy or even the progenitor of the burst.

SUPERB involves the real-time streaming of Parkes data to the NCRIS-supported gSTAR supercomputer at the Swinburne University of Technology, which exploits graphics processing unit (GPU) technology. SUPERB uses GPUs because searching for transient phenomena like pulsars and FRBs requires intensive data processing. Thankfully these tasks also exhibit high degrees of parallelism, which makes them well suited to many-core and multi-core architectures like GPUs.

Image: FRBs have a characteristic sweeping signal, shown in the final inset 'waterfall plot'. The difficulty in pinpointing where FRBs come from requires a multi-telescope approach to zoom-in to the true position, in this case an elliptical galaxy.

State-of-the-art spectrograph reveals population of stars dying too young

In one of the closest and brightest clusters of stars in the Milky Way, an international team led by an Australian PhD student made a startling discovery. Large numbers of helium burning stars in the globular cluster M4 are dying sooner than expected. The premature stellar deaths will occur in the sodium-rich/oxygen-poor stars, which is not predicted by the models, prompting scientists to revisit our accepted view of stellar evolution.

The researchers used a state-of-the-art new Australian-built instrument, the NCRIS-funded high efficiency and resolution multi-element spectrograph (HERMES) on the Anglo Australian Telescope (AAT), to decipher the chemical composition of the stars through careful inspection of the starlight.

Until HERMES, this research would have been impossible to conduct on the AAT and would have required the use of larger overseas telescopes. But HERMES has maintained the AAT as an internationally competitive telescope with the ability to analyse at high-resolution the chemical composition of up to 400 stars at a time.

The researchers intend to develop new computer simulations that improve upon existing models and which will better demonstrate what is happening in these stars' cores.

Image below: **Globular cluster M4.**
Credit: **NOAO/AURA/NSF www.sciencedaily.com/releases/2016/05/160518165243.htm**

Oldest stars in the Milky Way?

Astronomers may have found the oldest stars in the Milky Way. The stars, discovered in the galaxy's bulge, suggest that extraordinarily powerful explosions known as hypernovas might have dominated the Milky Way during its youth. The oldest stars in the Universe are poor in elements heavier than helium, called "metals" by astronomers, that are created within stars and ejected when they die.

Astronomers have previously discovered extremely metal-poor stars in the outer regions, or "halo," of the Milky Way. It is expected that the central region of the Galaxy should contain large populations of extremely these stars, but until now, they had not been detected, partly because of the distance and intervening dust that obscures Earth's view of the Galactic centre. In addition, finding metal-poor stars is like searching for a needle in a haystack, because they are vastly outnumbered by metal-rich stars.

In this ground-breaking study, research led by ANU student Louise Howes, and published in the journal Nature in November 2015, have identified stars from the cosmic dawn in the Milky Way's bulge for the first time. The researchers started by scanning about 5 million stars using the ANU SkyMapper telescope to flag about 14,000 potential extremely metal-poor stars. The Anglo-Australian Telescope was then used to hone in on about 500 stars, each with less than one-hundredth the amount of iron seen in the sun. Finally, the Magellan Clay telescope in Chile closely analysed 23 of the most metal-poor bulge stars to determine their chemical composition. Time on these telescopes was funded by NCRIS.

Interestingly, the researchers found that these bulge stars were as poor in carbon as they were in iron. In contrast, metal-poor stars in the galaxy's halo are often rich in carbon, possessing as much as the sun does. This result was not predicted and suggests that the earliest stars might not have died in normal supernovas, but in even bigger explosions known as hypernovas.

Image: **The Galactic centre obtained using SkyMapper data.**
Image credit: **Chris Owen (ANU/RSAA).**

Tricky transients reveal gas structures

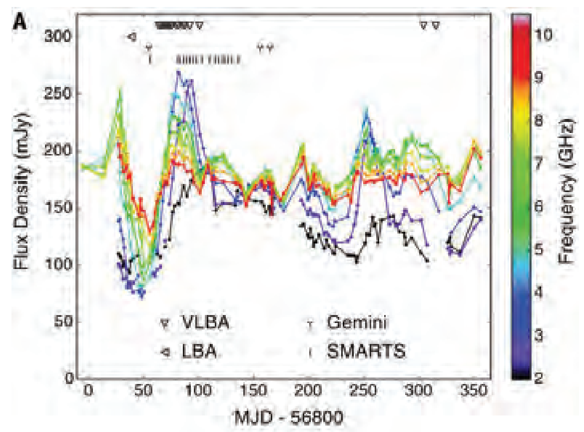
A CSIRO-led team peered at a distant quasar for months and discovered that although the radio light observed with the Australia Telescope Compact Array (ATCA) showed dramatic changes, the optical light observed with the Gemini South telescope remained stable. Their results, published in the journal *Science*, suggest that there are elongated structures ("noodles") of electrically charged particles within our Milky Way galaxy that scatter the radio waves and cause flickering, but do not affect the optical light.

This finding exploited a new radio survey technique that allows transient events to be observed in real time. The transients of interest are known as extreme scattering events (ESE), in which the radio images of distant quasars become modified by interstellar plasma in our own Milky Way galaxy. Lumps in the plasma work like lenses, focusing and defocusing the radio waves, making them appear to strengthen and weaken over time. Finding ESEs has typically required a lot of telescope time and a great deal of luck. And very little is known about the lumps themselves because most properties of the lens are measurable only while the ESE is in progress.

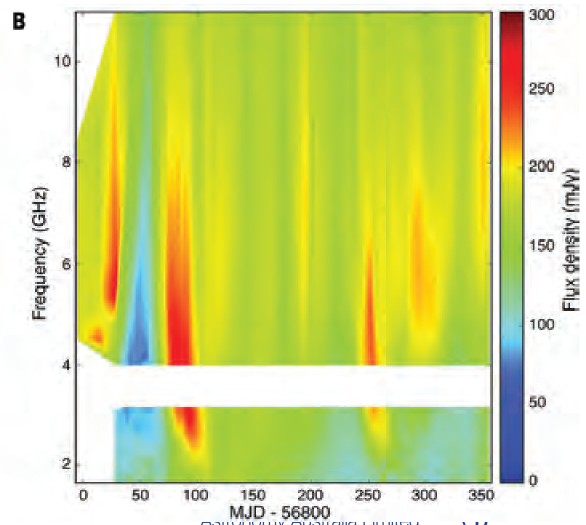
CSIRO's Keith Bannister and his team developed an efficient technique for finding ESEs in real-time. This exploited the ATCA wideband receiver and correlator, which were recently upgraded with support from NCRIS. They found that when a plasma lensing event is in progress, the radio spectrum of the background source changes from a featureless continuum to one that is highly structured. The team obtained baseline spectra by observing approximately 1000 active galactic nuclei once per month, then searched for spectra that didn't match the baseline.

Image: **One hundred four epochs of ATCA radio data of PKS 1939–315.**

Just two months into the survey, the team discovered an ESE towards a quasar in the constellation of Sagittarius. Catching the lensing event in full swing, the team observed it with other radio and optical telescopes and were able to estimate the shape of the lump in the interstellar plasma. The discovery confirmed that the shape of the lump causing ESEs must indeed be peculiar. It could be flat, like a sheet of lasagna viewed edge-on, or a hollow cylinder like a noodle, or a spherical shell, like a hazelnut. Identification of these structures has challenged our understanding of the dynamics of interstellar gas in the Milky Way.



A) Multifrequency light curve comprising nine 64-MHz channels centered every 1 GHz from 2 to 10 GHz. Thermal noise at each point is 0.5 mJy, less than the thickness of the lines. The symbols above the light curve indicate the days when follow-up observations were obtained using the VLBA, the Gemini 8-m telescope, and the SMARTS 1.3-m telescope.



(B) *Dynamic spectrum averaged to 4-MHz frequency resolution, sampled on a 1-day grid, and linearly interpolated between observing epochs. The thermal noise at each spectral point is 2 mJy. ATCA receivers do not cover the frequencies 3.1 to 3.9 GHz.*

The Year in Highlights:

Industry & Commercialisation

Australia has a history of leadership in developing innovative technologies for astronomical research, driven in large part by our national facilities the Australian Astronomical Observatory (AAO) and the Australia Telescope National Facility (ATNF). The next decade will present new opportunities to build on Australia's strong pedigree in the engineering and technology disciplines that enable astronomy, and to accelerate collaboration with local industry, leading to more jobs and high-end human capability. The industry engagement activities highlighted in this report are representative of a range of activities undertaken in 2015/16 by AAL member organisations.

> "The next generation of billion-dollar facilities like the SKA and ELTs provide significant opportunities for Australian industry to secure substantial contracts for the construction of the necessary infrastructure, instrumentation and technology." (Australian Astronomy Decadal Plan 2016-2025)

Astronomers collaborating with urban planners

Cloud cameras developed and operated by Australia as part of the Pierre Auger Observatory have developed into commercial use by urban planners. Knowledge developed over many years on the infra-red properties of the sky is enabling researchers to provide useful information to agriculturalists on frost and to advise cities on the serious problem of the overnight retention of heat in urban areas. The latter is known as the Urban Heat Island effect and results in many deaths world-wide at times of heat waves.

The basic requirement for cloud detection at night is to use the infra-red radiation levels from the sky to select regions of low radiation levels ('cold' regions) which are clear sky areas. This requires knowledge of how the 'temperature' of the clear sky varies, both with meteorological conditions and angular distance from the horizon, together with similar knowledge of various forms of cloud cover. The infra-red temperature determines how an area cools overnight and is a significant factor in shaping the development of micro-climates.

This work has resulted in a collaboration with Adelaide University, Flinders University, and support from the Adelaide City Council, to study heating and cooling issues in Adelaide. It also led to collaboration with architects to study heat flow through green roofs. Two papers were published in 2016 and the results are in demand by overseas urban planners.

Technology transfer from robotic observatories to solar energy farms

Former UNSW PhD student Colin Bonner's start-up company Fulcrum-3D has had a number of recent commercial successes that can be traced directly or indirectly to Colin's time working on the NCRIS-supported PLATO project. Fulcrum-3D now employs 6 people full-time, and an additional 6 people part-time. Their main product is a sonic radar, sold in 10 countries. They are one of only three manufacturers that meet international standards for a calibrated sonic instrument.

Fulcrum-3D recently obtained a $1M ARENA grant and used it to design and produce an instrument called CloudCAM (similar in some respects to an instrument developed for PLATO) that is used to provide real-time forecasting for solar energy farms. CloudCAM has shown 4-5% improvements in power output from the solar farms, with 90% reduction in battery usage, since it is able to predict when diesel backup needs to come on-line.

Fulcrum-3D is in the process of lodging several patents for this device and is exploring a possible collaboration with the UNSW PLATO team for remote power systems in Turkey based on the PLATO design and Hatz 1B-30 engines.

Image: **The Fulcrum-3D CloudCAM with irradiance and temperature/humidity sensors. CloudCAM has sophisticated software that provides real-time forecasts of the effect of clouds on solar energy power output, thereby allowing diesel backup to be brought on-line in time to cover outages from cloud.**

Sustainable energy powers radio astronomy

The Murchison Radio-astronomy Observatory (MRO) in outback Western Australia (WA), 350 km inland from the coastal town of Geraldton, is home to the Square Kilometre Array (SKA) precursor radio telescopes the Australian Square Kilometre Array Pathfinder (ASKAP) and the Murchison Wide-field Array (MWA). It will also soon be home to a hybrid power station. While the MRO is ideal for radio astronomy, powering sensitive instruments in a remote location presents quite a challenge.

The power station is being built by Horizon Power (a wholly owned corporation of the WA Government) and Perth-based small-to-medium-size enterprise, EMC Solar Construction. The project is supported by the WA Government, principally through its Royalties for Regions program, and the Australian Government's Education Investment Fund.

EMC Solar Construction has designed and built a 1.6 megawatt (MW) solar array of 5280 solar panels and a lithium ion battery system that will deliver power at a rate of 1 MW with a storage capacity of 2.5 MW hours – making it the largest lithiumion storage battery in Australia (other than those in submarines).

Horizon Power has also commissioned EMC Solar Construction to design and build a second photovoltaic array of 250kW to be integrated with its diesel gensets and the much larger array and battery system. The photovoltaic arrays, together with the battery, will be capable of supplying up to 40% of all site power. All equipment needs to be very carefully shielded to protect the radio quiet environment of the MRO.

EMC Solar Construction has long experience delivering off-grid renewable energy solutions, but the strict radio frequency interference (RFI) measures required by this project were something new. CSIRO's specialist engineers worked closely with EMC Solar Construction's highly skilled staff to design and implement workable RFI shielding solutions. The project has been an opportunity for EMC Solar Construction to grow its skills and showcase its capabilities – the company has grown from 12 to 52 employees in the time of this collaboration.

Image: **The two-hectare solar array soon to be powering the MRO. Image credit – CSIRO**

Big Data partnership between university and tech giants driving innovation

The Cisco Internet of Everything Innovation Centre (CIIC) is a ~$30M partnership between founding members Curtin University, Woodside, and CISCO. Launched in 2015, it brings together start-up companies, industry experts, developers and academics to develop cloud, analytics, cyber security and ICT solutions to a range of research and commercial challenges.

CIIC is building on the expertise of radio-astronomers involved in the Square Kilometre Array (SKA) activities and the Australian SKA precursor projects, and extending this to a range of discipline areas including the oil and gas industry, agriculture, health, and smart and connected cities.

In 2015/16, CIIC successfully commissioned a 100 Gbps data link between the Square Kilometre Array precursor telescope, the Murchison Widefield Array (MWA), and the Curtin campus in Perth located 1000 km away. This is a major milestone on the path to developing ICT solutions for the SKA.
The link was established with the support of AARNet and CSIRO, and has achieved a coherent data stream – meaning digital data packets sent from the MWA were arriving on time and in sync. CIIC is now working on developing next-generation software signal processing solutions for the MWA and, ultimately, the SKA.

Image: **CIIC partners (L-R): Woodside Senior Vice President, Strategy, Science and Technology, Shaun Gregory; Curtin University Vice-Chancellor, Professor Deborah Terry; and Cisco Senior Vice President and Chief Security and Trust Officer, John Stewart, at the Cisco Internet of Everything Innovation Centre.**

Capturing the Cosmos

The NCRIS-funded Murchison Widefield Array is featured, along with the SkyMapper Telescope, in *Capturing the Cosmos*, a major planetarium show that was released around Australia in March 2016 and has been viewed by tens of thousands of people.

Narrated by Geoffrey Rush, it explores CAASTRO's cutting edge research about our place in space, and features stunning time-lapse photography taken by renowned astro-photographer Alex Cherney. The show was created by Museum Victoria's Melbourne Planetarium in partnership with the ARC Centre of Excellence in All-Sky Astrophysics (CAASTRO).

Image: **School children inside the Dome at the Melbourne Planetarium show.**
Image credit: **Museum Victoria, Paoli Smith Photography**

The Year in Highlights:

Outreach

Australian astronomers are very active in public outreach, undertaking a wide variety of activities aimed at a range of audiences, from primary, secondary and tertiary students to members of the general public. Outreach engages the community in the exciting research being undertaken at NCRIS-supported facilities and helps inspire the next generation of scientists. In 2015/16, NCRIS-supported facilities undertook a large number of science outreach activities, including the highlights below.

Australian Gemini Image Contest

The popular Australian Gemini Image Contest took a new direction in 2015 by inviting the Australian public to vote on one of four categories of object to be observed: an individual galaxy, a galaxy pair, a planetary nebula, or another type of nebula. The Australian Gemini Cosmic Poll was hosted by the science and media technology platform http://thinkable.org. More than 100 votes were received at the end of which the "individual galaxy" category came out on top. The observations were made active in the Gemini queue, and a "Live from Gemini" video was available with regular updates on AAO's Facebook and Twitter accounts. The final stunning image shows the starburst galaxy NGC 3310, with current star formation highlighted by the inner pink spiral. This was a fitting way to mark the end of Australian usage of Gemini's queue mode.

Record pulsar observation from Geraldton

In April 2016, CSIRO put its Parkes radio telescope into the hands of students, teachers and anyone who happened to stop by during the Geraldton Science Festival. This Festival aims to build awareness about the importance of science, technology, engineering and maths in our everyday lives. The event included a marathon ten-hour observing program – the longest PULSE@Parkes session that either of them can remember.

PULSE@Parkes (PULsar Student Exploration online at Parkes) lets high school students control the Parkes Radio Telescope and observe pulsars under the guidance of professional astronomers. The students' observations feed into a database used to carry out studies of such astronomical phenomena as pulsar glitches, timing noise, pulse profile stability over long time scales and extreme nulling phenomenon. The data are also included in other projects such as gamma-ray observatory support and for the Parkes Pulsar Timing Array project.

It's almost ten years and hundreds of observing hours since the first PULSE@Parkes program: the students' observations have made a tremendous contribution to the kind of research that can only be done with well designed longitudinal studies.

Image: **Gemini Telescope's starburst galaxy NGC3310**
Image credit: **Australian Astronomical Observatory.**

The Year in Highlights:

International Engagement

The Australian Astronomy Decadal Plan 2016-2025 is titled *"Australia in the era of global astronomy"* in recognition that we have entered an era where the scale of next-generation astronomical facilities is too large for individual nations to assume sole ownership. Fostering strong international relationships is therefore crucial to ensuring Australia retains an active voice in the direction of large multinational infrastructure facilities and is also critical to allowing Australia to remain globally competitive in astronomical research. Outlined below are recent examples of international linkages that are driven by AAL and NCRIS supported projects.

Australian technology developed for SKA in demand overseas

CSIRO's multi-award winning phased array feed (PAF) receivers, designed for its Australian Square Kilometre Array Pathfinder (ASKAP) radio telescope, are in growing demand on telescopes around the world.

Through an agreement with Germany's Max Planck Institute for Radio-astronomy (MPIfR), CSIRO has built a PAF receiver for the 100-metre Effelsberg telescope. The receiver is being commissioned on Parkes prior to delivery to Germany and be used to do real science, including searching for Fast Radio Bursts (FRBs) – something for which Parkes is particularly famous, having detected the majority of all FRBs detected so far. PAF receivers are ideal for FRB searching as they can "see" a much larger part of the sky instantaneously than traditional receivers – a great advantage when conducting a blind search. This Effelsberg PAF has been specially designed for the radio environment in Germany and will operate in the 1150 – 1800 MHz band. It also features a bespoke GPU processing cluster and a 2.5Tb/s Ethernet switch. MPIfR is developing the specialized data processing software – the high data rates produced by a PAF require real-time data management and archiving.

MPIfR sees PAFs as a key technology for future astronomy, and an exciting step towards a new generation of receivers with capabilities not previously possible. CSIRO sees this collaboration as helping demonstrate the potential for CSIRO's PAF technology to be used on other radio telescopes – including the SKA.

In 2015/16, CSIRO's iconic Parkes radio telescope was granted the status of 'SKA pathfinder' by the International SKA Organisation in recognition of its role in testing innovative new PAF systems.

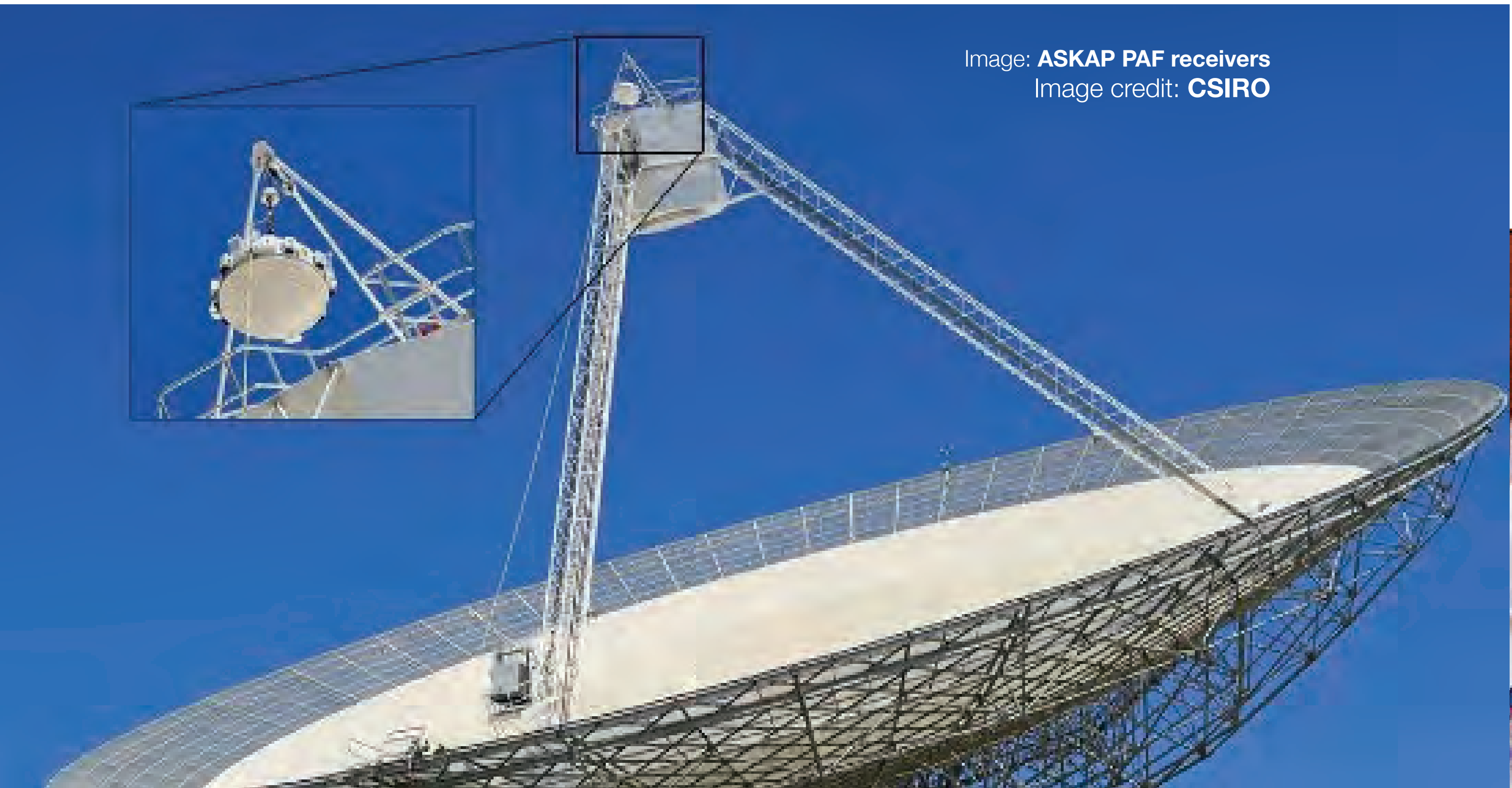
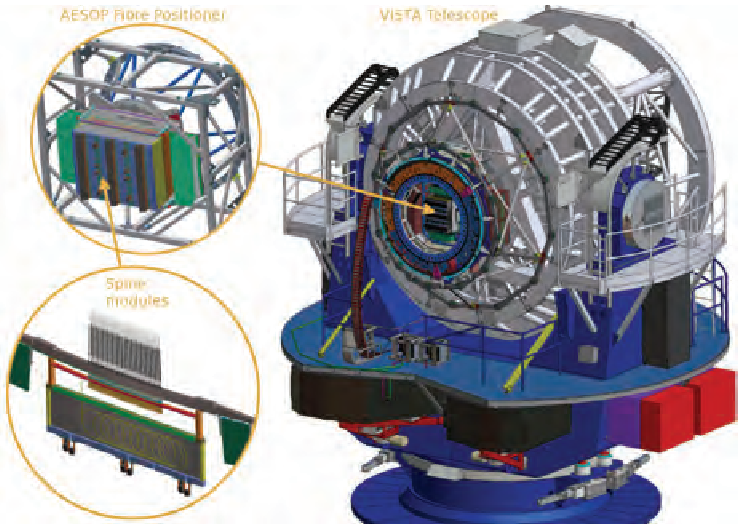


Image: **ASKAP PAF receivers**
Image credit: **CSIRO**

Local patented technology in use by ESO

Innovative technology developed by the Australian Astronomical Observatory's (AAO) will be used on a new instrument being developed for one of the world's most advanced telescopes run by the European Southern Observatory (ESO).



The instrument, 4MOST (the 4-metre Multi-Object Spectroscopic Telescope), will rely on a unique fibre positioner called AESOP, which is based on patented AAO technology that has previously been installed on Japan's 8-metre Subaru telescope and will be used on the future 25-metre Giant Magellan Telescope.

Involvement in this international collaboration grants 8 nominated Australian astronomers and their teams the right to participate in any of the surveys using the 4MOST instrument. In addition, it enables Australia to lead one of the 4MOST surveys, WAVES, to study 2 million galaxies to better understand dark matter and galaxy formation.

Australia is the only one of the 13 international partners in the 4MOST consortium that is not a European Southern Observatory member, and reflects our high degree of innovation and international engagement.

Australia-China establish joint research centre

In September 2015, Australia and China signed an agreement to establish a new joint research centre in astronomy, called ACAMAR (Australia-China Consortium for Astrophysical Research). This body will facilitate and boost bilateral collaborations in areas ranging from Antarctic astronomy to radio telescopes such as the 500-metre FAST telescope in China and the future Square Kilometre Array.

The centre was formed through an agreement between the ARC Centre of Excellence for All-sky Astrophysics (CAASTRO) and the National Astronomical Observatories of the Chinese Academy of Sciences (NAOC). AAL serves on ACAMAR's management body, and helped build momentum towards this centre through a memorandum of understanding regarding Antarctic astronomy that AAL entered into with China in 2013.

Image: **ACAMAR Meeting, China**

Facilities and Projects

AAL supports construction, upgrades, instrumentation development, maintenance and operations at a number of facilities located around Australia. AAL also manages, represents and supports the interests of Australian astronomers in a number of international projects and facilities. These activities align with the national research infrastructure priorities of the Australian Astronomy Decadal Plan and are made possible by support from the Australian Commonwealth Government via programs such as the National Collaborative Research Infrastructure Strategy (NCRIS). The following pages outline facilities and projects to which AAL committed funding in 2015/16.

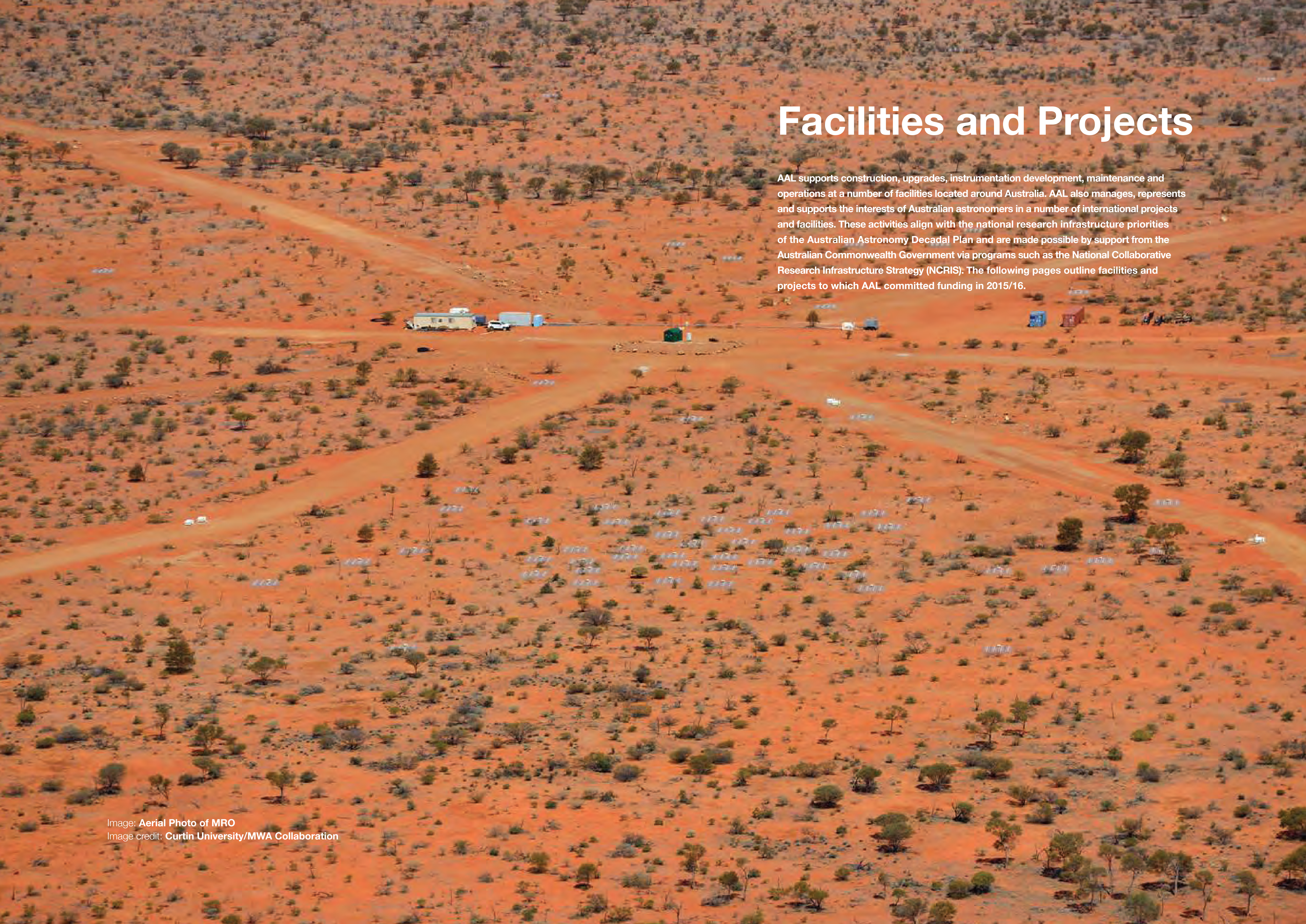


Image: **Aerial Photo of MRO**
Image credit: **Curtin University/MWA Collaboration**

Image: **Keck propagates its adaptive optics laser as the milky way rises behind it, lit by a setting moon.**
Image credit: **Sean Goebel, www.sgphotos.com**

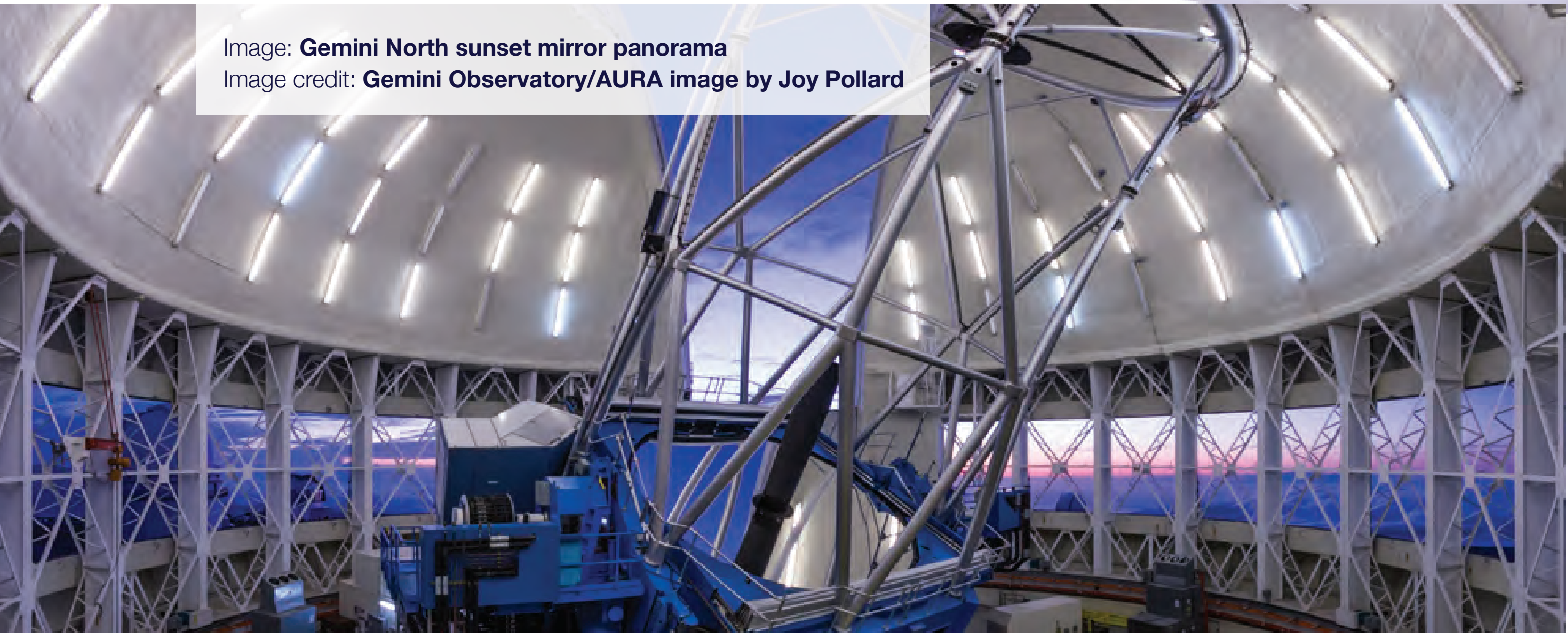
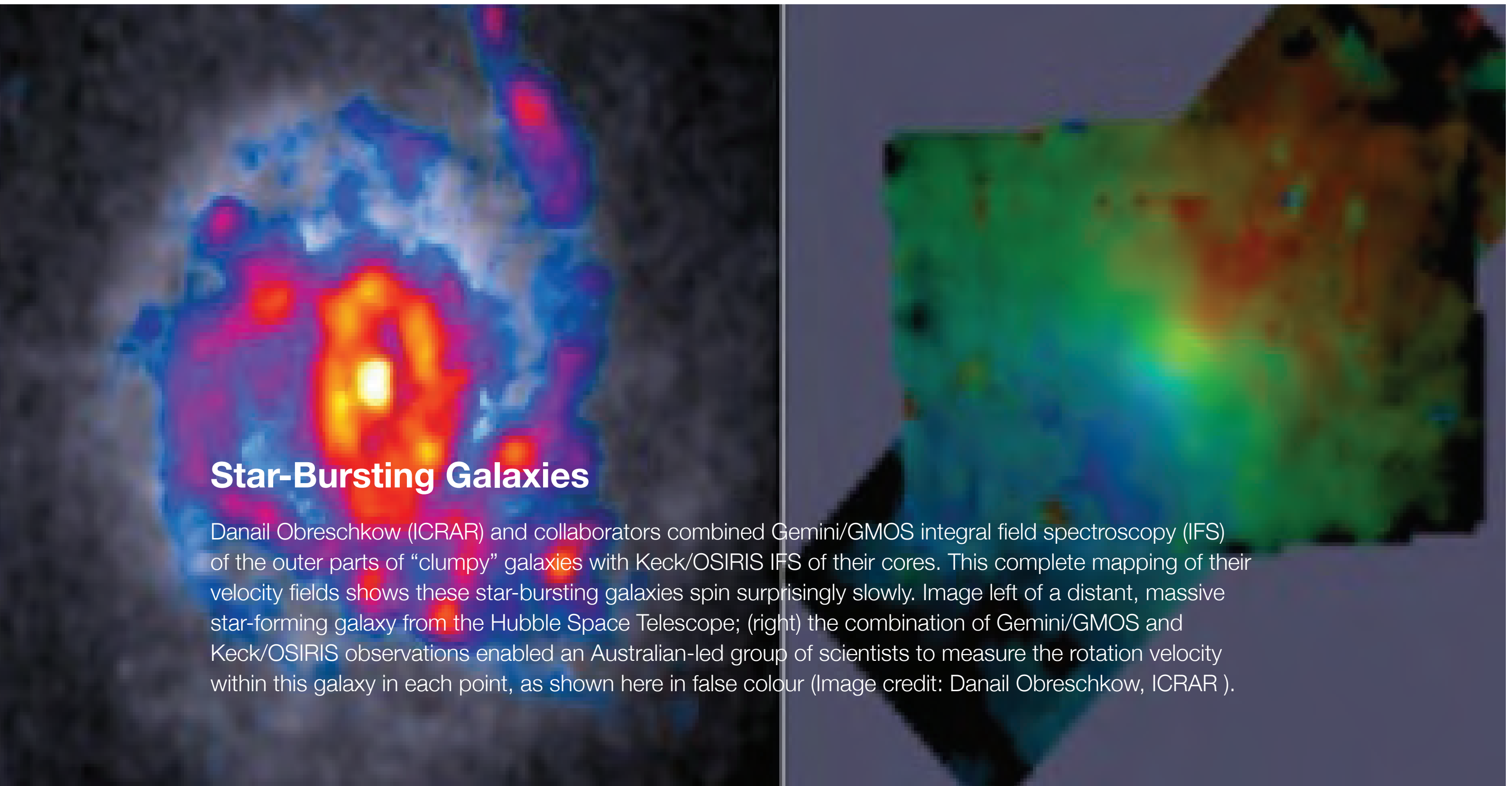


Image: **Gemini North sunset mirror panorama**
Image credit: **Gemini Observatory/AURA image by Joy Pollard**



Star-Bursting Galaxies

Danail Obreschkow (ICRAR) and collaborators combined Gemini/GMOS integral field spectroscopy (IFS) of the outer parts of "clumpy" galaxies with Keck/OSIRIS IFS of their cores. This complete mapping of their velocity fields shows these star-bursting galaxies spin surprisingly slowly. Image left of a distant, massive star-forming galaxy from the Hubble Space Telescope; (right) the combination of Gemini/GMOS and Keck/OSIRIS observations enabled an Australian-led group of scientists to measure the rotation velocity within this galaxy in each point, as shown here in false colour (Image credit: Danail Obreschkow, ICRAR).

Optical Telescopes: 8-metre Telescopes

The Australian Astronomy Decadal Plan 2016-2025 identifies five top-level science infrastructure priorities, including partnership equating to 30% of an 8-metre class optical/infrared telescope. Australia has a strong track record in optical/infrared astronomical science and instrumentation, including high-impact research from 8-metre telescopes and numerous contracts to build cutting-edge instrumentation for overseas optical/infrared facilities. Partnership in an 8-metre telescope would allow Australia to build on this strong foundation and capitalise on Australia's strategic investment in the Giant Magellan Telescope by ensuring that we have the required expertise, science foundation, and technical capacity.

In 2015/16 AAL purchased time on world-class telescopes Keck and Magellan via $2.2M of NCRIS and Department funds. Approximately $32.0M of Commonwealth funds have purchased time on Gemini, Magellan and Keck 8-metre telescopes since 2006.

Partnership opportunities

Securing partnership in an 8-metre-class telescope at the level specified in the Decadal Plan is a key priority for AAL. Therefore, during 2015/16, AAL continued engaging with 8-metre-class facilities including Keck, Subaru, Magellan, and the European Southern Observatory to explore options for future Australian partnership.

Until such partnership is achieved, AAL maintains a core level of 8-metre access through arrangements to purchase or secure time on three world-class telescopes Gemini (7 nights/year), Magellan (15 nights/year) and Keck (15 nights/year). This access amounts to a total of 67 telescope nights, or approximately 15% of an 8-metre telescope in 2016. Despite current access to these world-class telescopes in 2015/16, the total level of Australian access will be approximately half of the 30% target in the Decadal Plan. Hence, AAL's continued focus on exploring potential funding sources and partnership options with suitable facilities around the world.

Demand for time of the Gemini, Magellan and Keck telescopes was strong with subscription rates averaging 300%.

Keck Time Allocation Committee

In addition to securing access to time on Keck telescopes in 2015/16, AAL reached an agreement with ANU and Swinburne University (who each have 15 nights/year on Keck) to establish a national merit based program to manage all Australian access to these telescopes. The Keck Time Allocation Committee (KTAC) was established to provide a single interface for Australian-based astronomers who wish to request access to the total of forty-five nights available on Keck in 2016. The process is designed to facilitate larger programs and broader collaborations to maximise the scientific return from Australia's engagement with the Keck telescopes. Already, the first year of this joint Keck TAC shows very encouraging evidence of benefits, including enabling greater flexibility in scheduling time, greater collaboration within the community, longer programs, and greater efficiency than if each of the 3 partners ran their own independent time allocation program.

International Telescope Support Office

In 2015/16, AAL supported staffing and operations of the International Telescopes Support Office (ITSO) which is hosted and operated by the Australian Astronomical Observatory (AAO), and is responsible for coordinating Australia's usage of international telescopes for which AAL has negotiated access agreements. In 2015/16, this included time on the Gemini 8.1 metre telescopes in Hawaii and Chile; 15 nights per year on the Magellan 6.5 metre telescopes in Chile; and the time on Keck telescopes available through the KTAC scheme. In 2015/16, ITSO coordinated the first two semesters of time allocated by KTAC. Following a sharp learning curve for ITSO staff in the first semester the process is running quite smoothly.

The 2016 ITSO/AAO Observational Techniques workshop was held at the AAO in May 2016, providing observing training to Australian-based PhD students and early career researchers. The broad training covered optical/infrared facilities offered to Australian astronomers, data archives, tips on writing successful proposals, data reduction, hands-on tutorials, data analysis tools, public outreach, and more. Participants also got the chance to test their newly acquired skills during the data reduction challenge. A total of 38 participants were present for the workshop along with 19 presenters. The program along with slides from the various presentations can be found on the workshop website at www.aao.gov.au/conference/OTW2016.

Optical Telescopes:

The Anglo-Australian Telescope

Commissioned in 1974, the Anglo-Australian Telescope (AAT) is operated by the Australian Astronomical Observatory. The telescope is Australia's front-ranked National optical/infrared facility, comprising an exceptionally high-quality 4-metre telescope equipped with a suite of state-of-the-art instrumentation, including the HERMES and AAOmega spectrographs. Its excellent optics, exceptional mechanical stability and precision computer-control make it one of the finest telescopes in the world. The AAT has provided a foundation for Australia's excellence in optical astronomy since it was commissioned, and NCRIS-supported maintenance and new instrumentation has allowed the AAT to continue producing leading science.

In 2015/16, AAL supported the upgrade and maintenance of AAT and critical major maintenance of the 2dF fibre cable system that channels light into the two most heavily used AAT spectrographs: HERMES and AAOmega, using NCRIS funds ($400K). AAL has a long history of supporting AAO to develop innovative new AAT instrumentation as well as undertake vital maintenance of the AAT building, allocating over $12.5M of funding from the Commonwealth government since 2007

Progress 2015/16

2015/16 was a year of significant achievement both scientifically and in instrumentation on the AAT. The large flagship surveys being conducted on the AAT – SAMI, GALAH, OzDES, and 2dFLens (previously funded by AAL through NCRIS) all made significant progress, publishing key results.

OzDES Survey

The OzDES is a large survey at the AAT, using the 2dF fibre positioner and AAOmega spectrograph to observe tens of thousands of sources in the 10 deep fields of the Dark Energy Survey. OzDES has just completed its third observing season, and is now half way through its allocation of 100 AAT nights and is well on its way to obtaining the data it needs. By the end of the survey, the AAO expects to obtain the redshifts of over 2,500 Type Ia supernova, spectroscopically identifying over 200 of them. OzDES is also making significant progress in monitoring over 800 AGN and finding several rare objects.

GALAH Survey

The Galactic Archaeology with HERMES (GALAH) Survey had its second observing anniversary in November 2015. With solid experience in 2dF+HERMES, observing is a smooth process. Data reduction is reliable, with new data automatically reduced the day after they are taken. A new direction in the data analysis has driven significant progress, with initial stellar parameters produced along with the data reduction. The process for determining the final stellar parameters and detailed abundances will employ a combination of classical line-profile analysis and machine learning. These results will enable the GALAH team to produce exciting high-impact publications, for which they have begun showing preliminary results at conferences.

239 researchers used the Anglo-Australian telescope in 2015/16.

Critical Upgrades

The Two-degree Field (2dF) multi-fibre positioner distributes the optical signal from the prime focus of the AAT to the AAOmega and HERMES spectrographs. HERMES and AAOmega occupy a high proportion of the total AAT observing time and together, they make the AAT the world's best instrument for wide-field spectroscopic surveys.

The NCRIS-funded upgrade of the 2dF and HERMES fibre commenced in late January 2016 and is expected to be completed in mid-2017. The upgrade will replace optical elements on the 2dF end of the fibre cable to increase the number of astronomical objects that can be observed simultaneously, therefore, improving observing efficiency. The project will also develop the capability to replace damaged fibres within the Optical Cable, as they occur.

In addition, NCRIS funding enabled the replacement of aging components of the AAT infrastructure and instrumentation with more efficient, reliable, safe, and better-performing systems and components. This upgrade helped to ensure that the AAT and its suite of world-class instruments continue operating effectively to meet the needs of the astronomy community well into the future.

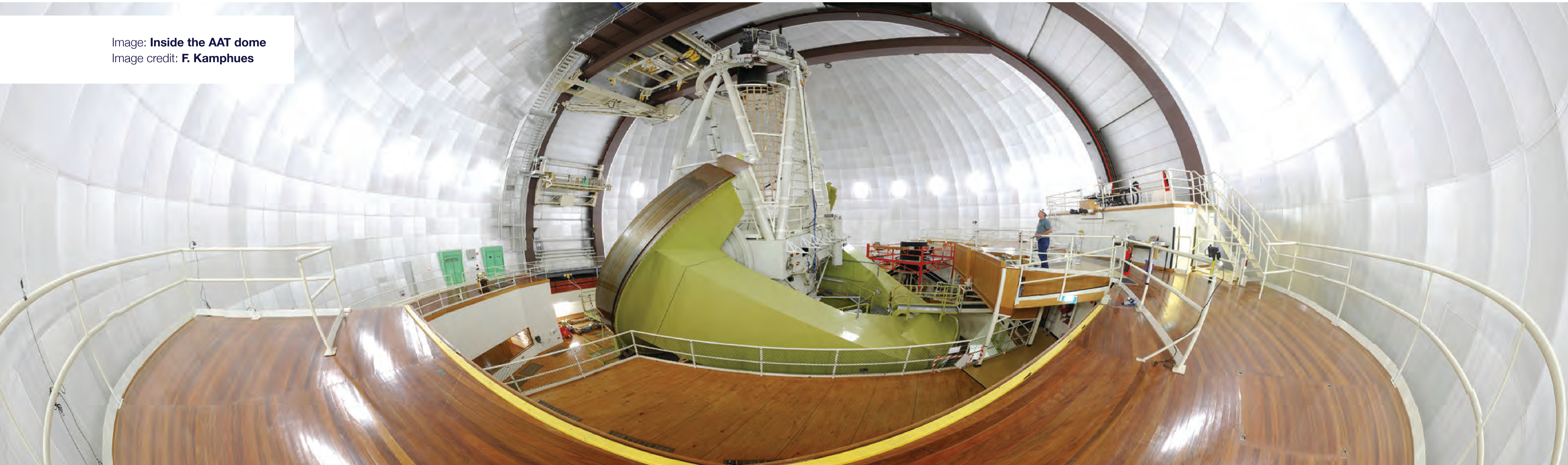


Image: **Inside the AAT dome**
Image credit: **F. Kamphues**

Optical Telescopes:

The Future

Giant Magellan Telescope

The Giant Magellan Telescope (GMT) is a next generation optical/infrared super-giant telescope that promises to revolutionise our view and understanding of the universe. It will be located in northern Chile at Las Campanas Observatory. Owned by the Carnegie Institution for Science, Las Campanas is home to the twin 6.5 metre Magellan telescopes. Perched at an elevation of over 8,000 feet (2400m) on the Andes mountain range, the site is known for clear weather and dark skies and is insulated from the light pollution that poses a major obstacle to ground-based optical astronomical research.

Upon completion, the GMT will utilize cutting-edge optics technology to combine seven segmented 8.4 metre mirrors forming a single optical surface of 25 metres in diameter with a total collecting area of 368 square meters. The GMT will be capable of achieving ten times the resolution of the Hubble Space Telescope. GMT will embark on a mission of discovery to explore the origins of the chemical elements, the formation of the first stars and galaxies, and the mysteries of dark matter and dark energy. Poised to be the first "Extremely Large Telescope" to begin operations, and designed to have an operational lifespan of 50 years or more, GMT is will provide unprecedented clarity and sensitivity for the observation of astronomical phenomena. First light and commissioning for the telescope is expected by 2023, with GMT becoming fully operational by 2025. The GMT will be critical in enabling Australian-based astronomers to tackle many of the key science questions identified in the 2016-2025 Decadal Plan for Australian astronomy.

The GMT Organisation is an independent organization created by an international consortium of leading academic and research institutions with the mission of funding, engineering, constructing and operating the world's largest optical telescope. Australia is a 10% partner in GMT, via the Australian National University (ANU) and AAL, which are both 5% partners. The Australian Government has invested approximately $93M of Commonwealth funding in the billion-dollar GMT project, which has positioned Australia to play a leadership role in GMT science and instrumentation. During 2015/16, NCRIS funding supported continued engagement in GMT governance, including representation on the GMTO Board as the project progresses through the first phase of construction and actively seeks new funding and partners to realise the full budget.

Progress 2015/16

The billion-dollar GMT project reached an important milestone with the commencement of the construction phase in November 2015. This was triggered by the 11 international founders committing over $500M towards the project.

On November 11, 2015, GMTO broke ground on the future site of the Giant Magellan Telescope in a ceremony attended by leading scientists, senior officials, the President of Chile, and Australian representatives: Professor Anne Green (Chair AAL Board) and Prof Matthew Colless (ANU).

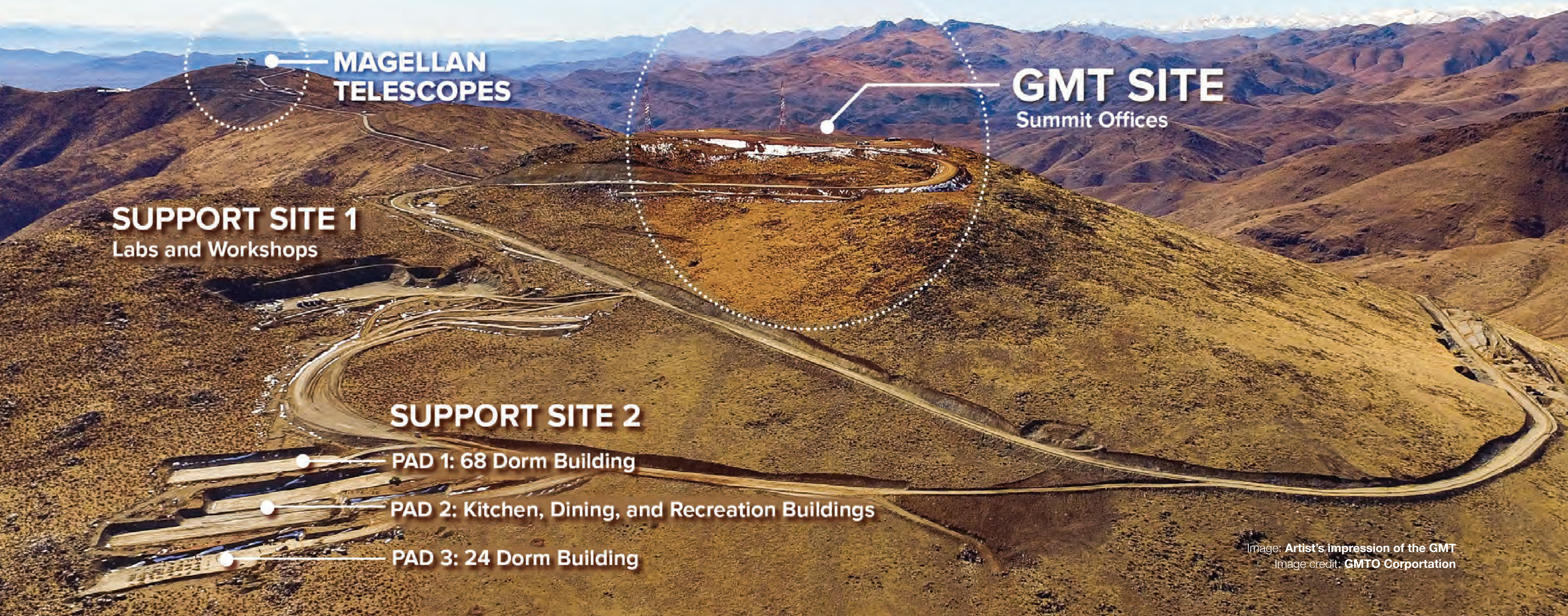


Image: **Artist's impression of the GMT**
Image credit: **GMTO Corportation**

Image: **Artist's impression of the GMT**
Image credit: **GMTO Corporation**

Following the ground-breaking ceremony, the GMTO team working on the telescope site have been busy finalizing civil works. The scintillometer system is also now complete and is taking valuable data. In addition, the GMTO Pasadena team of approximately 100 people moved into its new headquarters in Pasadena, California.

The telescope's mirror segments are in various stages of fabrication at the University of Arizona. One giant mirror has been polished to meet its exacting specifications. Three others are being processed, and production of the additional mirrors will commence at the rate of one per year. In September 2015, the mirror lab casted the fourth GMT mirror segment and in December 2015 it was removed from the furnace to begin preparation for polishing, a process that will take three to four years to complete.

During 2015/16 GMTO continued to engage closely with the astronomical community and in October 2015 they held the Third Annual GMT Community Scientific Meeting in California. The GMTO hosts the Community Science Meetings each year to encourage discussions on a wide range of topics covering astronomy and astrophysics and to stay informed in state-of-the-art research in the field. The event is also an opportunity to reach beyond the consortium to engage the broader astronomical community. Over 120 people gathered to discuss resolved stellar populations and galaxy formation, including galactic archaeology and the use of galaxies as cosmological probes.

Australian instrumentation

The GMTIFS (GMT Integral Field Spectrograph) instrument from the ANU will be one of six GMT first-light instruments for which Conceptual Design Studies have been undertaken. GMTIFS will be used with the GMT's Laser Tomography Adaptive Optics (LTAO) system and the primary instrument is an adaptive-optics-corrected near-infrared integral-field spectrograph. The ANU is also contracted to develop the GMT LTAO system concept.

The AAO-designed MANIFEST (MANy-Instrument FibrE SysTem) is a general-purpose fibre-positioning system, to feed the GMT instruments such as GMACS (the proposed optical imaging spectrograph), NIRMOS (the proposed near-infrared imaging spectrograph) and G-Clef (high resolution optical spectrograph).

Image: **Groundbreaking ceremony**
Image credit: **GMTO Corporation**

Image: **MWA antenna tiles**
Image credit: **Curtin University/MWA Collaboration**

SKA Pathfinders

Australia is involved in, and playing a critical role, in one of the biggest billion-dollar astronomy projects, the Square Kilometre Array (SKA), which will be partly built in Australia with local industry and regional engagement. On the path to the next-generation radio telescopes, the Decadal Plan highlights the importance of the “pathfinders” for SKA, namely: the two SKA official precursor telescopes, the Australian SKA Pathfinder (ASKAP – capital value $188M) and the Murchison Widefield Array (MWA – value $50M). Australia has invested heavily in these precursors, which are acting as test-beds for advanced technology solutions for the SKA and demonstrating the exceptional conditions in outback Western Australia for radio astronomy. In addition, they are scientifically powerful instruments in their own right, making data available to more than a quarter of Australian astronomers and hundreds of international collaborators.

NCRIS funding in 2015/16 allowed continued operations of the two Australian SKA precursos, CSIRO’s ASKAP and The Murchison Widefield Array (MWA).

Murchison Widefield Array

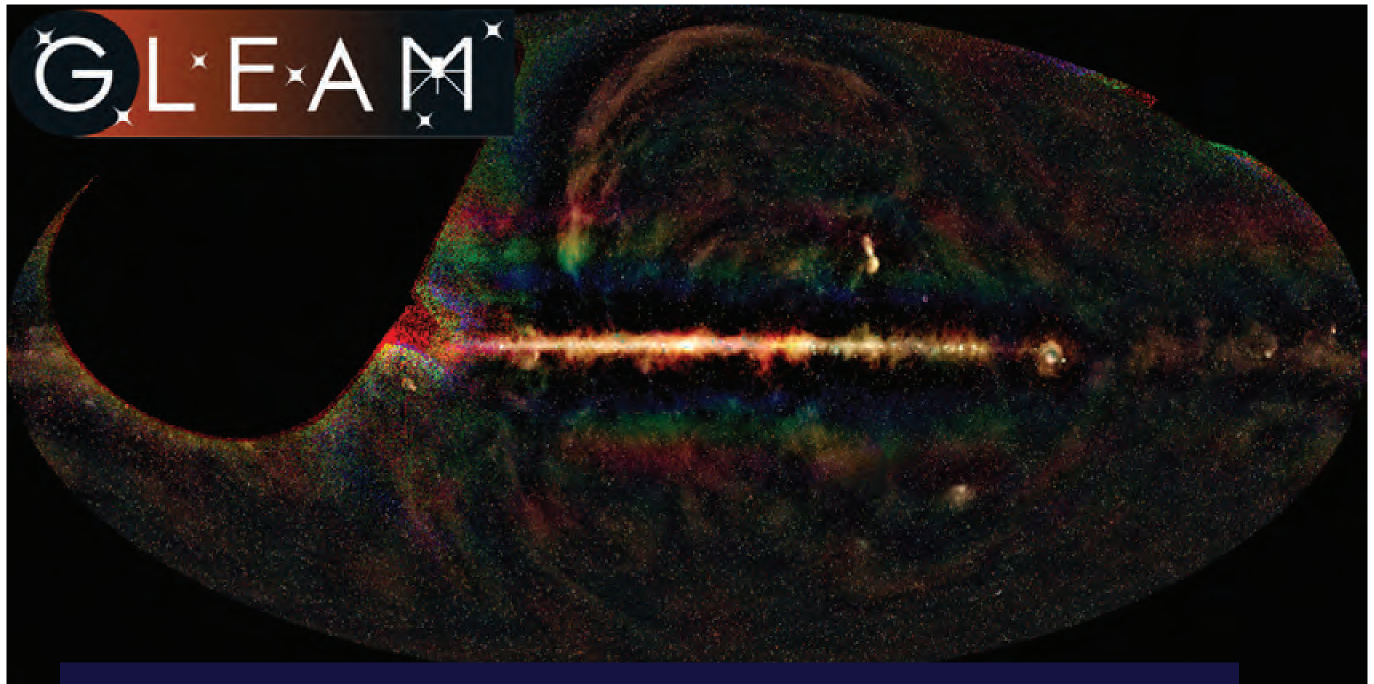
The Murchison Widefield Array (MWA) is a low-frequency radio telescope, located at the Murchison Radio-astronomy Observatory (MRO) in Western Australia, the planned site of the future Square Kilometre Array (SKA) low-band telescope will be built, and is one of several telescopes designated as a precursor for the SKA. The MWA has been developed by an international collaboration between 13 research institutions in four countries (Australia, India, New Zealand and the United States) and is led by Curtin University.

The telescope collects radio waves with low frequencies between 80 and 300 MHz via 4,096 antennas, split up into 128 groups of 32 called ‘titles’ that are spread as far as 3 km apart. It is designed to have a wide field of view on the sky and to be highly versatile and adaptable through signal processing rather than through moving parts.

The MWA is performing large surveys of the entire Southern Hemisphere sky and acquiring deep observations on targeted regions. It enables astronomers to pursue four key science objectives. The primary endeavour is the hunt for intergalactic hydrogen gas that surrounded early galaxies during the cosmological epoch of reionization. The MWA will also provide new insights into our Milky Way galaxy and its magnetic field, pulsing and exploding stellar objects, and the science of space weather that connects our Sun to the environment here on Earth.

During 2015/16, AAL supported MWA operations through $0.6M of NCRIS funding. AAL has previously provided $8.6M to enable MWA construction and early operations, using Commonwealth funding under NCRIS, EIF and other infrastructure programs.

GLEAM image: **This 3-colour image of the southern galactic plane is from Hindson et al., 2016 (“A Large-Scale, Low-Frequency Murchison Widefield Array Survey of Galactic H ii Regions between 260 < l < 340”). The image shows the brightness of radio emission at 3 different radio frequencies observed by the MWA in the GLEAM survey.**



GLEAM image: **Credit Natasha Hurley-Walker and the GLEAM team. This radio 3-colour image is a mosaic of the entire sky observed by the MWA for the GaLactic and Extragalactic All-sky MWA (GLEAM) survey. GLEAM survey data is the basis of many MWA science programs, from studies of nearby Galactic supernova remnants to supermassive black holes in distant galaxies.**

Progress 2015/16

In 2015/16 the MWA achieved its third year of full operations. A total of 4246 hours of observing were completed during the year, with 4.5 petabytes of data collected in support of more than 23 projects. Since commencing operations in mid-2013, MWA has taken more than 9800 hours of data totalling more than 10 petabytes in support of the science programs awarded time on the telescope.

These data are stored at the Pawsey Supercomputing Centre in Perth, where the MWA has been allocated 20 petabytes of dedicated storage. Storing the data close to the processing resources helps to minimise the requirement to move large amounts of data around Australia and the world. This will be a key challenge faced by the SKA, and therefore the MWA and other precursor and pathfinder projects are investing considerable intellectual capital in devising ever more efficient means of handling, transporting and processing data as instrument users come to grips with radio-astronomy in the ‘big-data’ era.

MWA’s NCRIS-funded operations delivered high availability and reliability throughout the year despite the challenging environmental conditions at the MRO. A number of measures implemented through the course of the year improved the resilience of the instrument to the high summer temperatures and these vital lessons will feed into the development and design of future instruments, including SKA.

With a focus on growing the MWA Collaboration and its impact, this year has seen significant effort invested in making the MWA as accessible to as broad a user community as possible. Two MWA data reduction workshops were run and are available for those new to or interested in working with MWA data.

In late 2015 an ‘MWA Phase 2’ proposal to increase the number of MWA ‘tiles’ from 128 to 256 and to increase the array size from 3km to 6km was funded by the Australian Research Council (ARC). The projected cost of the extension is $2.8M, with $1.8M to be provided by the MWA partners and $1M by the ARC. Although not funded by AAL, funds were used to supported the operations of the MWA team.

The MWA collaboration produced an impressive 31 refereed publications in 2015/16 with 63 Australian co-authors and 94 international collaborators.

The ‘Phase 2’ expansion of the MWA was well underway by mid-2016. With the support of volunteer effort from around the Collaboration, 72 new tiles have been added to the MWA core region. The new tiles are arranged into two compact hexagons to enhance the array’s sensitivity in support of EoR experiments. The 72 tiles were completed in mid-June and will be progressively cabled and commissioned through July and August. The array will then be reconfigured by disconnecting 72 tiles on longer baselines and replacing them with the new core tiles to commence an enhanced EoR observing program around October 2016.

The remaining 56 Phase 2 tiles will be installed on longer baselines, nearly doubling the extent of the array and significantly improving its resolution. These tiles will be located areas that have not previously been subjected to Heritage and environmental assessments and approvals. These processes are underway and MWA Phase 2 will be completed in late 2016.

Australian SKA Pathfinder

CSIRO's Australian Square Kilometre Array Pathfinder (ASKAP) located at the remote radio-quiet Murchison Radio-astronomy Observatory (MRO) in Western Australia, is designed to be one of the world's fastest and most powerful radio telescopes. ASKAP is pushing the boundaries of scientific and engineering innovation, developing revolutionary technologies that will transform radio astronomy, and prepare for the future Square Kilometre Array telescope. ASKAP comprises an array of 36 dish antennas, each 12 metres in diameter and fitted with state of the art phased array feeds (PAFs), that work together as a single instrument. ASKAP is both a demonstrator for the award-winning Australian PAF technology and a world-class instrument in its own right. Approximately one in four Australian-based astronomers are investigators on ASKAP science projects and will be able to use ASKAP's unique capabilities to address high-impact topics in astronomical research.

In 2015/16, AAL invested $5.2M of NCRIS funds through CSIRO towards the costs of operating ASKAP and supporting user engagement to ensure that the community has the capability to exploit the full potential of ASKAP. AAL has previously provided a total of $25.9M Commonwealth funds to support ASKAP construction and operations.

Progress 2015/16

The last twelve months have seen great progress with the ASKAP telescope. The first science papers from BETA (Boolardy Engineering Test Array) were published, demonstrating not only the great potential of phased-array feeds (PAFs) for radio-astronomy, but also the unique radio-quiet environment of the MRO.

The second-generation (Mark II) of PAF receivers rolled off the production line and 12 of these are now commissioned, poised to start the ASKAP Early Science Program. The Mark II design combines improved performance and reliability with reduced cost.

During 2015/16, the ASKAP commissioning and early science team (ACES) ran a series of community workshops on: (i) ASKAPsoft testing; design of the user interface to ASKAP; consolidation of ASKAP commissioning plan (Oct 2015); and (ii) Introduction to Mark II data; assessment of those data; imaging; continuation of ASKAPsoft testing (Dec 2015).

NCRIS funding also supported the salaries and living costs of CSIRO staff working at the MRO (electrical, electronics, mechanical technicians and engineers) and utilities at both the MRO and Boolardy Accommodation Facility sites.

Technical highlights during the year included: an impressively successful suppression of radio frequency interference (RFI) signal originating from GPS satellites using manipulation of beam weights; successful use of the prototype on-dish calibration system to measure the relative gains of PAF elements; and production of a 25 beam image using Mark II PAFs to image ASKAP's entire field of view. Another highlight of 2016 was the ASKAP PAF team's receipt of the 2016 Chairman's medal, CSIRO's highest annual award.

Following the re-baselining of the Square Kilometre Array project early in 2015 it became clear that ASKAP will now remain a stand-alone instrument for longer than originally envisaged. The component of SKA to be built in Australia will be SKA-LOW, a low-frequency array comprising around 130,000 dipoles. Negotiations are underway for the Convention under which the SKA Observatory will be constituted, and in late 2015, the Australian Government announced $294M of funding for hosting the SKA, as part of its National Innovation and Science Agenda.

As described under Science Highlights, ASKAP and MWA telescopes were two of the first telescopes in the world to make rapid follow-up observations of the first-ever gravitational wave detection. The gravitational wave detection is one of the most significant scientific discoveries of the last century. These NCRIS funded facilities will continue to exploit their unique capabilities, including wide-field of view, fast survey speed, high resolution and sensitivity, and southern hemisphere location, to play an exciting role in the emerging field of gravitational wave astronomy.

Image: **ASKAP**
Image credit: **CSIRO**

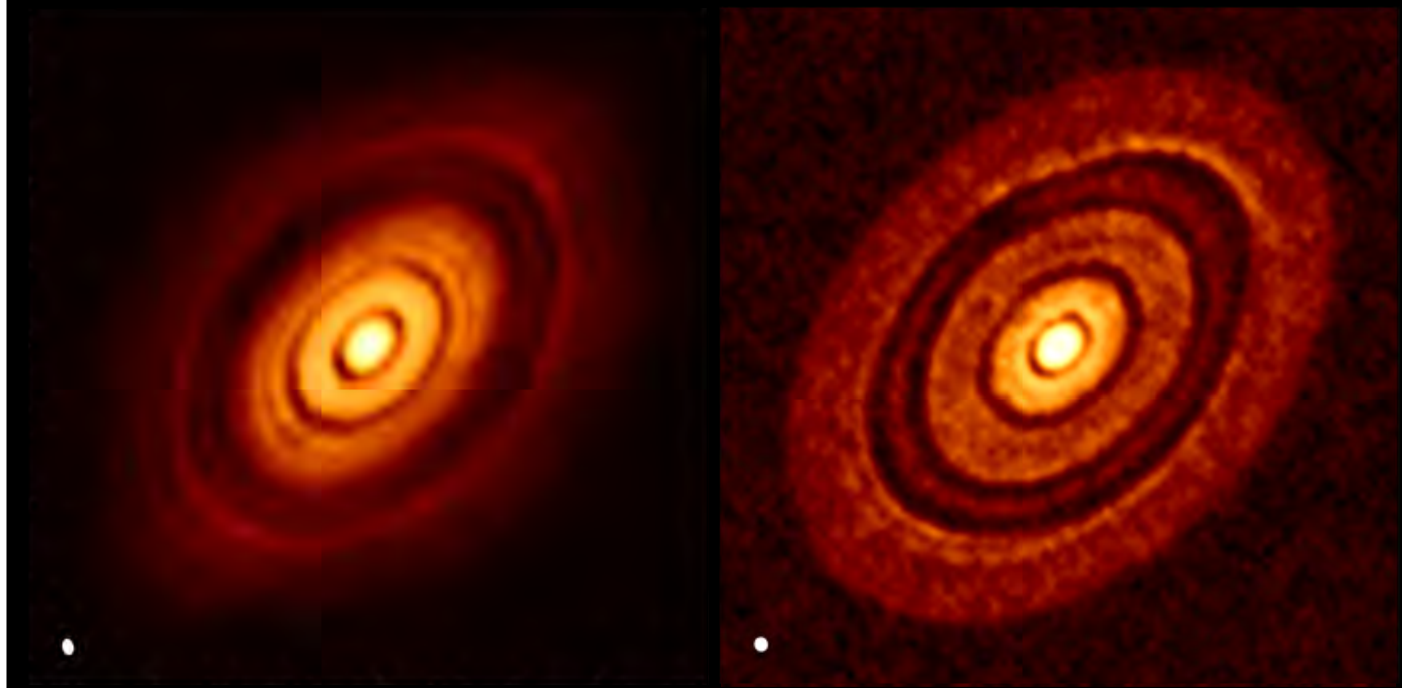
Data & Computing Infrastructure

High Performance Computing

Astronomy is a highly data- and compute-intensive discipline, with significant demands for underpinning eResearch infrastructure. These demands will accelerate in the next decade as new telescopes come online that generate unprecedented data volumes and require significant HPC time for data processing and theoretical modelling to interpret the data. The 2016-2025 Decadal Plan for Australian Astronomy showed that theoretical and computational astrophysics has grown to become a focus across all areas of strength in Australian astronomy, and represents approximately one third of research impact. Australian astronomical research is enabled by a range of HPC infrastructure, including the peak facilities at the National Computational Infrastructure (NCI) and the Pawsey Supercomputing Centre, and the NCRIS-supported GPU-supercomputer at Swinburne University of Technology (gSTAR) which provides National astronomy-dedicated time.

Image: **(Left) First light observations of the HL Tau protoplanetary disc at mm wavelengths from the Atacama Large Millimetre/submillimetre Array (ALMA) telescope, showing alternating bright and dark rings of material orbiting a newborn star.**

(Right) Computer simulations of three Saturn-mass planets embedded in a protoplanetary disc, which carve gaps and rings that closely match the observed features. The close match between simulations and observations strongly suggest that we are witnessing, for the first time, the birth of planets around a nearby young star.”



Observed image

Credit: ALMA partnership et al. (2015)

Our simulation

Dipierro, Price, Laibe, Hirsh, Cerioli & Lodato (2015)

GPU Supercomputer for Theoretical Astrophysical Research (gSTAR)

The GPU Supercomputer for Theoretical Astrophysics Research (gSTAR) was built to provide the Australian astronomy community with a next-generation computing cluster based on graphics processing unit (GPU) technology to solve some of the most complex problems in astrophysics. Within the HPC landscape, the emerging technology of GPUs offered an affordable path to a massive boost in processing power.

During 2015/16, AAL provided $0.4M of NCRIS funding to support ongoing operations of gSTAR. In early 2016, AAL provided over $0.1M of NCRIS funding to develop the gSTAR Data Management and Collaboration Platform (gDMCP). AAL has previously supported the construction and operations of gSTAR, with a total of $2.0M of Commonwealth funding. gSTAR is fully operational and the overall capital value is approximately $3.5M.

Progress 2015/16

The gSTAR/SwinSTAR supercomputing system provides the equivalent of ~7,500,000 CPU hours per year for the dedicated use of the national astronomy community.

gSTAR is a highly productive facility with continued growth in usage and publications, with 99 facility-related refereed astronomy papers published in 2015/16.

In addition, gSTAR has users from industry and other capabilities, including Intelligent Transport Systems (collaborating with VicRoads), Brain Sciences (e.g research into dyslexia and anaesthesia), Fluid Structure and Oceanography (linking with the oil/gas and marine engineering industries).

During 2015/16, the facility uptime was greater than 99% and usage grew from 250 to over 300 researchers. 244 of these were Australian based, almost 70 were international users and over 50% were students.

A focus over the past year was to leverage the astronomy-focused skills and resources of the gSTAR/SwinSTAR NCRIS funded team to provide targeted training and support to help the astronomy community as well as other capabilities and industry get more value from gSTAR/SwinSTAR. This included technical support for the user community, optimization of software and hardware, pro-active engagement through workshops and training, priority project development, high-level data management support and provisioning of open-access to project data, coordinating the Astronomy Supercomputer Time Allocation Committee (ASTAC).

In 2015/16, AAL continued to support the management of the Astronomy Supercomputer Time Allocation Committee (ASTAC) that uses a merit-based allocation process to assign time for astronomy projects at these three facilities.

Development of the gSTAR Data Management and Collaboration Platform (gDMCP) commenced in 2015/16 with construction of a user interface, support for Australian Access Federation authentication, integration with the gSTAR Lustre filesystem and the first public release of gDMCP (https://data-portal.hpc.swin.edu.au). In an effort to make research data open, transparent and reusable, Swinburne signed an agreement with the Publications of the Astronomical Society of Australis (PASA) to provide free hosting on gDMCP for datasets associated with articles published in PASA.

gSTAR continues to be a pivotal component of the NeCTAR All-Sky Virtual Observatory (ASVO) e-Research project, and is the host of the Theoretical Astrophysical Observatory (TAO) node of ASVO.

"Building the Astronomical Data Archives of the Future" panel at the international Astronomical Data Analysis Software and Systems (ADASS) conference, October 2016. This ASVO-led panel included colleagues from major international VO projects and tackled issues around the future of VO in the big data era. Left-to-right: Simon O'Toole (AAO), Jessica Chapman (CASS), David Ciardi (LSST), Richard White (MAST), Tamas Budavari (SDSS), Amr Hassan (Swinburne), Christian Wolf (ANU), Yeshe Fenner (AAL).
Image credit: **Andrew Green, AAO.**

"Optical data from the Southern Sky Survey, obtained using the SkyMapper telescope at ANU's Siding Spring Observatory comprises the most detailed and sensitive digitised map of the southern sky at optical wavelengths," Dr Fenner, COO, AAL
Image Credit: **nectar.org.au**

All-Sky Virtual Observatory

The Australian Astronomy Decadal Plan 2016-2025 recognises that it is critical to develop infrastructure to provide access to big datasets from next-generation telescopes, and to enable multi-wavelength astronomy by connecting independent data hubs through interoperable data access services and tools. The All-Sky Virtual Observatory (ASVO) takes a step in this direction by supporting a growing collection of theoretical and observational datasets, via a distributed network of ASVO "Nodes".

The ASVO project currently involves Astronomy Australia Limited, Swinburne University of Technology, the Australian National University, National Computational Infrastructure, and the Australian Astronomical Observatory. ASVO has received funding from the Australian Commonwealth Government though the National eResearch Collaboration Tools and Resources (NeCTAR) Project, the Australian National Data Service (ANDS), and the National Collaborative Research Infrastructure Strategy. In 2015/16, AAL invested $0.3M of funding to ASVO development and operations. A total of $3.1M of Commonwealth funding has been provided to ASVO.

Progress 2015/16

ASVO comprises a growing number of "Nodes"

ASVO-TAO Node: The Theoretical Astrophysical Observatory (TAO), developed at Swinburne and launched in March 2014, houses a growing ensemble of theory data sets and galaxy formation models, with tools to map the simulated data onto an observer's viewpoint, and the application of custom telescope simulators including SkyMapper.

During 2015/16, the number of TAO users grew to over 300, of whom almost 200 were international users. TAO version 3.0 is now under development, which will make major enhancements to the infrastructure to accommodate hydro-dynamical simulations that will open up TAO for new science questions, including the survey science projects of the Australian radio facilities MWA and ASKAP.

ASVO-SkyMapper Node: The SkyMapper node is providing Australians with priority access to a world-leading digital atlas of the Southern sky. The SkyMapper Southern Survey is using ANU's SkyMapper telescope at Siding Spring Observatory to take images in a unique set of optical filters, and building catalogues of the one billion objects it detects. Astronomers can use the tools of the ASVO to inspect and download the images and measurements. In addition, the ASVO is enhancing the productivity of astronomical research by cross-matching SkyMapper objects with numerous other catalogues, to put a more complete, multi-wavelength view at the fingertips of investigators. Through the ASVO, Australians have exclusive access to this data for a year before it becomes accessible by the rest of the world.

In July 2015, ANU unveiled the SkyMapper Test Data Release that covers a third of the southern sky that includes data from nearly 20,000 images taken between March 2014 and March 2015. This was followed by the first full data release in mid 2016. Over 500 users have accessed SkyMapper data.

ASVO-AAT Node: The Anglo-Australian Telescope (AAT) Node is being developed by the Australian Astronomical Observatory (AAO). The AAT Node is developing an archive infrastructure and interface that is extensible and scalable, designed to meet the current and future needs of the astronomical community. This will be demonstrated by the deployment of two initial exemplar datasets (SAMI and GAMA survey data) that span the range of capabilities to be provided. The extensibility requirement ensures that, at the conclusion of the project, the AAO is capable of ingestion and deployment of all AAT surveys of major national significance through the AAT Node.

During 2015/16, the AAT-Node team successfully deployed the GAMA dataset for testing to the user testing group which is a cross section of the astronomical community. The SAMI web interface is currently in testing and will be released late 2016.

ASVO-MWA Node: AAL previously funded a now complete design study to determine the requirements for building the first radioastronomy Node of ASVO, which would support access to the complex data from the AAL-supported Murchison Widefield Array telescope. MWA is a precursor to the future Square Kilometre Array (SKA) and has already collected over 10 petabytes of data. MWA is proving to be a valuable test bed for both the telescope hardware and the associated eResearch infrastructure on the path to SKA. AAL continues consulting with stakeholders to determine the most effective and efficient way to implement the recommendations from the design study, and to secure the required funding.

Launched in 2014, ASVO now has over 700 active users from around the world.

Image: **A container with AST-3 telescope parts being loaded on a sled prior to the 1200km traverse to Dome A. The traverse arrived at Dome A on 31 December 2015, for a 21 day stay.**

Antarctic Astronomy

PLATeau Observatory

Located high on the Antarctic Plateau are a series of robotic observatories called PLATOs ("PLATeau Observatory") conducting year-round experiments completely robotically. This is one of the best sites in the world to undertake optical and infrared astronomy, due to the cold, dry and stable atmospheric conditions and is the only ground-based site from where terahertz observations can be made. Australian activities in the field of Antarctic astronomy have been supported by AAL over a number of years, including the development and operation of PLATOs (at Dome A, Dome Fuji, Ridge A) in collaboration with Chinese, Japanese, and US partners and Antarctic logistics agencies.

In 2015/16, AAL provided over $0.1M of NCRIS funding to the AAO for servicing and operations of PLATO-A at Dome A, supporting the Chinese led AST3 telescopes. AAL has previously supported the construction and operations of PLATOs and associated instrumentation, bringing the total of Commonwealth funding to approximately $1.9M.

Progress 2015/16

PLATO-A is based at China's Kunlun Station, Dome A. It supports a number of experiments, including the first two of three Antarctic Survey Telescopes (AST3) - wide-field, high-precision optical survey instruments, whose main science goals include the search for extra-solar planets and supernovae.

The AST3-2 telescope is fully operational and is now collecting astronomical data (over 110,000 images and 13 terabytes of data, with numerous supernova and transient sources detected already).

The AST3-3 project has progressed well over the last year. This is a strong international Antarctic astronomy partnership involving a consortium of Australian institutes who are building a near-infrared Kdark band camera for a telescope built by the Nanjing Institute of Astronomical Optics and Technology. A new PLATO module will be required to support this project.

The Australian NIRSPEC and HRCAM1 experiments have been returned to UNSW for refurbishment after successfully completing their initial deployments. A new ozone monitoring experiment was installed in January, and is working well. The NISM experiment, to measure the Kdark sky background worked well in 2015 and data is now being analysed.

The servicing mission by Chinese colleagues in early 2016, to prepare PLATO-A and the associated astronomical equipment for another year of operation, was very

successful and PLATO-A now has five new diesel engines, and a new battery pack. PLATO-A has worked with 100% uptime throughout the year, with the testing of two new higher-capacity diesel engines being particularly successful. International collaborations have also been strengthened throughout the year via many joint meetings, workshops, and conferences involving personnel from Australia, US, China, France, Japan, and New Zealand.

12 refereed journal articles were published in 2015/16 involving over 50 Australian and international authors from 17 institutions.

High-Energy Astrophysics

Australian scientists and engineers make unique and valued contributions as minor partners in a number of large, international facilities and projects. Modest investment to enable Australian involvement in such partnerships can often be an effective way to gain access to cutting-edge facilities, such as these high-energy astrophysics projects.

Cherenkov Telescope Array

Cherenkov Telescope Array (CTA) is a 200 M-Euro global initiative to build the world's largest and most sensitive high energy gamma ray observatory, now entering its pre-production phase. It will serve as an landmark new observatory to the astrophysics community and will provide new insights into the non-thermal high-energy universe. Over 1000 scientists and engineers from over 32 countries participate in the CTA project. The CTA-Australia consortium comprises six institutions, led by the University of Adelaide.

CTA will have a large discovery potential in key areas of astronomy, astrophysics and fundamental physics research. These include studies of the origin of cosmic rays and their impact on the constituents of the Universe, the nature and variety of black hole particle accelerators, the nature of matter and physics beyond the Standard Model, searching for dark matter, and effects of quantum gravity.

NCRIS 2015/16 funds supported Australia's active engagement with the CTA consortium during the pre-production phase of the CTA, including assisting with telescope commissioning at the CTA southern site, designing observing procedures and analysis, investigating atmospheric effects on CTA performance, designing key science projects in large-scale surveys, and commissioning a camera detector (purchased with ARC LIEF funds) for the CTA Small Size Telescopes. Funding for this project commenced in early 2016.

Progress 2015/16

The CTA-Australia consortium held its annual meeting in Adelaide in April 2016 to plan Australia's practical and scientific engagement with CTA. About 30 scientists and students attended the meeting. Discussion was devoted to Australian involvement in early work towards CTA's Key Science Projects, status reports from related multiwavelength activities, future funding plans via ARC and NCRIS, and Australian membership of the CTA Observatory (CTAO) governing Council.

Several CTA-Australian members played active roles in developing the science case documents for some of the Key Science Projects. This included projects devoted to the Large Magellanic Cloud, Dark Matter searches, Galactic Plane Surveys, and the overall Science Case document.

Pierre Auger Observatory

The Pierre Auger Observatory located in Argentina is a $150M international facility that observes ultra-high energy cosmic particles. It operates as a hybrid observatory with two major components, a ground-based system of 1660 large-area radiation detectors, plus a system of 27 4-metre diameter UV telescopes which track cosmic ray cascades as they pass through the atmosphere at distances of up to 40 km. Australia's involvement in this project supports the latter facility in providing detailed cloud cover information over the 3000 square kilometre area of the Observatory. The Observatory is a scientific collaboration between 18 countries around the world including the University of Adelaide.

The project is carried out through the use of NCRIS-funded long-wave infrared cloud cameras which scan the telescope fields of view every five minutes and the full sky at 15 minute intervals, to provide observers with real-time information on cloud conditions, and to fill the observatory cloud database which is used as part of the analysis stream for all users of data from the 27 UV telescopes. Four cameras operate on each shift night (after sunset and times of low moon illumination), one supporting each telescope site. Those sites are located with spacings of approximately 60 km.

With NCRIS-support, the University of Adelaide built cloud monitoring systems for the Observatory that were commissioned in 2013. In 2015/16, NCRIS funds enabled the continued support of operations and servicing of these critical cloud camera systems bringing the total amount of funding provided to the project through the Commonwealth to almost $0.2M.

Progress 2015/16

The infrared cloud cameras purchased through NCRIS funding have proved to have good performance and reliability. Calibrations of the on-site cameras continue to be improved with better flat-fielding and knowledge of the various camera field distortions. The cameras have matured from the development stage to reach routine operations.

The data from the large telescopes are presently being used to determine the composition of the cosmic rays which are detected at the highest energies. This is a major success for the Observatory and depends heavily on reliable atmospheric monitoring (including cloud). It had not been expected to be possible at these energies, where the composition of nuclei at typical distances of 40 km is commonly required. These data are now being used to interpret the directional properties of the cosmic ray beam which result from the structure of galactic and inter-galactic magnetic fields combined with the composition properties of the beam.

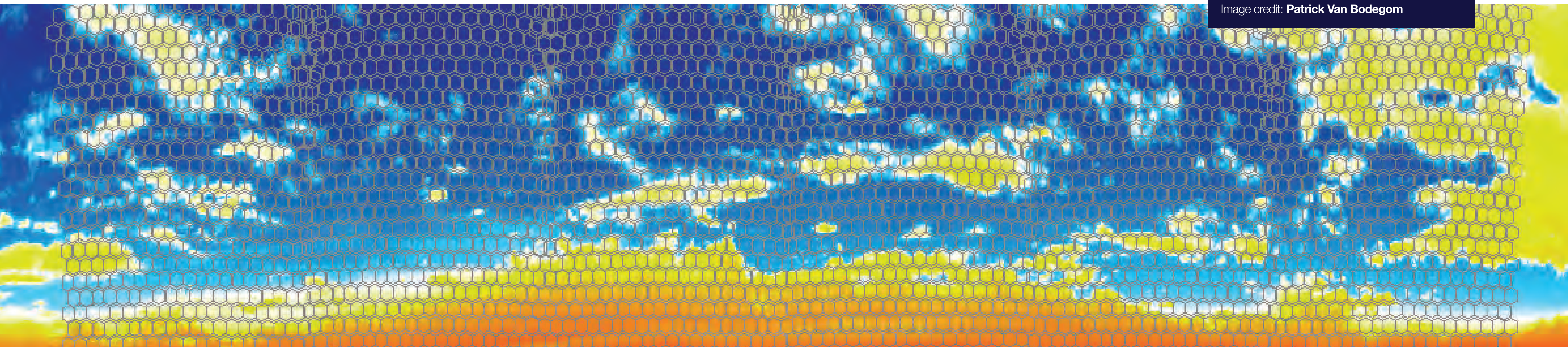


Image: **Cloud masks for the (overlaid) pixels of the six UV telescopes at one of the Pierre Auger Observatory fluorescence sites.**
Image credit: **Patrick Van Bodegom**

AAL Organisational and Governance Structure

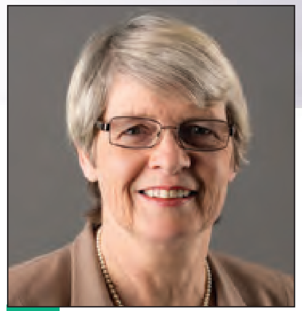
Image: **The NGC 6188 nebula and NGC 6193**
Image credit: **D.Malin, AAO**

Information about
Directors

Prof. Anne Green, Chair

BSc(Hons), PhD, FTSE, FASA, FAIP
Special responsibilities - Deputy Chair, member of the Radio Telescope Advisory Committee. From 20 November 2015, Board Chair and member of Audit and Risk Management Committee and Executive Remuneration Committee.

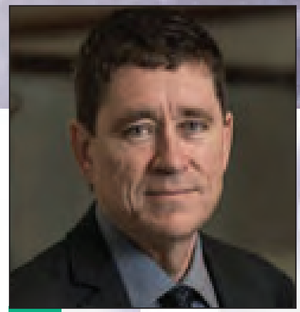
Prof. Anne Green is a Professor at the University of Sydney, and is a collaborator on a project to upgrade the Molonglo Telescope as a multi-tasking transient source detector that will be a pathfinder instrument to advance science and technology for the next generation of radio telescopes. Previously, she was the Head of the School of Physics, the Director of the Physics Foundation, and the Director of the Molonglo Observatory, all associated with the University of Sydney. Her research career spans more than 20 years in radio astronomy, with a focus on the structure and ecology of the Milky Way Galaxy. She has been an active member of several national and international astronomy advisory committees. She is currently a Member of the Australian Astronomical Observatory Advisory Committee and a Member of the Science Advisory Board of the Max Planck Institute for Radioastronomy, in Germany. Since 2007, she has been a Graduate Member of the Australian Institute of Company Directors.



Dr. Rosalind Dubs, Deputy Chair

BSc(Hons), Docteur ès Sciences, FTSE, FAICD
Special responsibilities – Member of the Audit and Risk Management Committee. Deputy Board Chair.

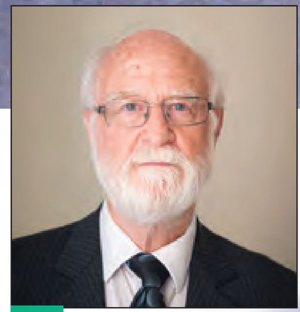
Dr Rosalind (Ros) Dubs is a professional company director, currently serving on the boards of ASX100 company Aristocrat Leisure Limited, government shipbuilder ASC Pty Ltd, and ANU Enterprise Pty Ltd. Her diverse business career spans a range of industries in publicly listed, private and government companies in Germany, France and Australia. For Thales SA, she was managing director delivering state-of-the-art navigational aids to 65% of the global aviation market, served as COO of the world's largest exporter of air traffic management systems, and sold missioncritical software and communications systems to the Australian Defence Force. At Airservices Australia, as director of operations support, she was responsible for all engineering operations across Australia. Dr Dubs was appointed to CSIRO's senior executive service in 1983. Within universities, she was Registrar of the ANU (1985-91), and Deputy Vice Chancellor (External Relations) at UTS (2007-09). Dr Dubs chaired the Australian Space Industry Innovation Council (2010-12), served on the Australian Astronomical Observatory Advisory Committee (2011-15), and was elected a Fellow of the Australian Academy of Technology and Engineering (2014).



Prof. Matthew Bailes

BSc(Hons), PhD
Special responsibilities – Member of the Computing Infrastructure Planning Working Group.

Prof. Matthew Bailes is an ARC Laureate Fellow at Swinburne University of Technology and leads the Centre of Astrophysics and Supercomputing's pulsar group. His main scientific interests concern the discovery and high precision timing of millisecond radio pulsars and the discovery of extragalactic fast radio bursts (FRBs). He is the theme leader of the Dynamic Universe for the ARC Centre of Excellence for All-Sky Astrophysics (CAASTRO) and the chair of the advisory board for the Collaboration for Astronomical Signal Processing and Electronics Research (CASPER). He collaborates extensively with MPIfR, the University of Manchester, the Cagliari Radio Observatory, Caltech and the CSIRO. Matthew is leading the redevelopment of the Molonglo Radio Observatory's correlator so that it can time pulsars and search for FRBs. He is the Australian lead of the Breakthrough Listen project to search for Alien transmissions with the Parkes radio telescope and leading the pulsar timing project on the South African Square Kilometre Array pathfinder the MeerKAT.



Prof. Ronald Ekers

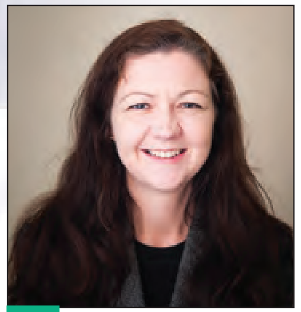
BSc(Hons), PhD (Astronomy), FAA, FRS
Special responsibilities: Member of the Radio Telescope Advisory Committee and member of Multi-Messenger Working Group.

Prof. Ron Ekers is a CSIRO Fellow and was Director of the Australia Telescope National Facility (1988-2003). He gained his PhD at the Australian National University in 1967. His professional career has taken him to the California Institute of Technology, the Institute of Theoretical Astronomy in Cambridge, UK, the Kapteyn Laboratory in Groningen, The Netherlands and the National Radio Astronomy Observatory, New Mexico USA. He was director of the VLA, the major national radio telescope in the USA (1980-87). He was elected a Fellow of the Australian Academy of Science, a Foreign Member of the Royal Dutch Academy of Science (1993), Foreign Member of the American Philosophical Society (2003) and a Fellow of the Royal Society (2005). He is past President of the International Astronomical Union. His research interests include extragalactic astronomy, cosmology, galactic nuclei, ultra high energy particle physics and radio astronomical techniques.

Dr Ian Chessell

BSc(Hons), PhD (Physics), FTSE
Special responsibilities: Member of the Executive Remuneration Committee and Audit and Risk Management Committee.

Dr. Ian Chessell followed a career in the Defence Science and Technology Organisation, retiring as Australia's Chief Defence Scientist in 2003. Dr Chessell served as a member of the Prime Minister's Science, Engineering and Innovation Council (2001-03) and in 2003 he was awarded the Centenary Medal for services to defence science. He was elected a Fellow of the Australian Academy of Technological Sciences and Engineering (2003). He was Chief Scientist of South Australia (2008-10) and was the inaugural Chair of the Goyder Institute for Water Research (2011-15). He is a currently a member of the Board of QinetiQ Pty Ltd (Australia). Dr Chessell has chaired a number of science reviews including Commonwealth reviews of National ICT Australia (2005), the Anglo-Australian Telescope (2006), and CSIRO's Climate Adaptation Flagship (2011).



Prof. Lisa Kewley

BSc(Hons), PhD (Astrophysics), FAA
Special responsibilities: Member of Optical Telescope Advisory Committee and an observer on the Keck Science Steering Committee.

Prof. Lisa Kewley is Professor and Associate Director at The Research School of Astronomy and Astrophysics, in the ANU College of Physical and Mathematical Sciences. She obtained her PhD (2002) and was a Harvard-Smithsonian Center for Astrophysics fellow and a NASA Hubble Fellow. She received the American Astronomical Society Annie Jump Cannon and Newton Lacy Pierce Awards, and an NSF Early Career Award. She was a 2011-15 ARC Future Fellow at ANU RSAA and was elected to the Australian Academy of Science (2014). She is currently an ARC Laureate Fellow. Her current policy roles include the AAO Advisory Committee, Keck Science Steering Committee, National Committee for Astronomy, Academy of Science Committee for Physics and Astronomy, and Editorial Board of the 2015-26 Australian Astronomy Decadal Plan. She leads a research program to understand the star formation and chemical history of the universe. Her research comprehensively covers theory, computation, and observation, including optical, radio and infrared.

Prof. Rachel Webster

BSc(Hons), PhD
Special responsibilities: Member of the Radio Telescope Advisory Committee.

Prof. Rachel Webster is a Professor at The University of Melbourne in the School of Physics where she leads the Astrophysics research group. She has had a stellar career teaching and researching astronomy for over 20 years. Originally gaining her PhD at Cambridge University, she spent productive years honing her skills in Canada at the University of Toronto, both teaching and doing research. Her work has been internationally recognized with internationally prestigious scholarships. She was also the inaugural AIP Woman in Physics Lecturer. She is a key member of an international consortium involving Australian, American, Indian and New Zealand astrophysicists to help design and build a new low frequency radio telescope (Widefield Array) at Mileura in Western Australia aiming to detect the first luminous sources in the universe. She is a member of the International Astronomical Union, and an Honorary Fellow of the Astronomical Society of Australia, the Royal Society of Victoria, and the American Astronomical Society. Rachel is a member of many committees, including The University of Melbourne Council, and the University College Council.

Retired
Directors

Prof. Brian Schmidt AC

BSc (Physics & Astronomy), A.M. in Astronomy, PhD (Astronomy), FAA, NAS, FRS
Retired AGM 20 November 2015
Special responsibilities: Board Chair and member of the Executive Remuneration Committee and Audit and Risk Management Committee.

Prof. Brian Schmidt is Vice-Chancellor of the Australian National University. Previously, he was an ARC Australian Laureate Fellow at the Australian National University and the Project scientist for the new SkyMapper Telescope, which is undertaking a comprehensive optical survey of the southern sky. His research has focused on the physics of distant exploding stars to trace the expansion of the Universe. He has received a variety of awards over his career culminating in his sharing the 2011 Nobel Prize for Physics. He has been an active member of several national astronomy and science bodies including the Major National Research Facilities selection panel, Australian Square Kilometre Array Steering Committee, Australian Decadal Working group on International Facilities and Mid-Term Review of the Australian Astronomy Decadal Plan. He is currently a member of the Commonwealth Science Council.

Prof. Brian Boyle

BSc(Hons), PhD, PSM, FAA
Retired AGM 20 November 2015
Special responsibilities: Member of the Audit and Risk Management Committee and observer on Magellan Council.

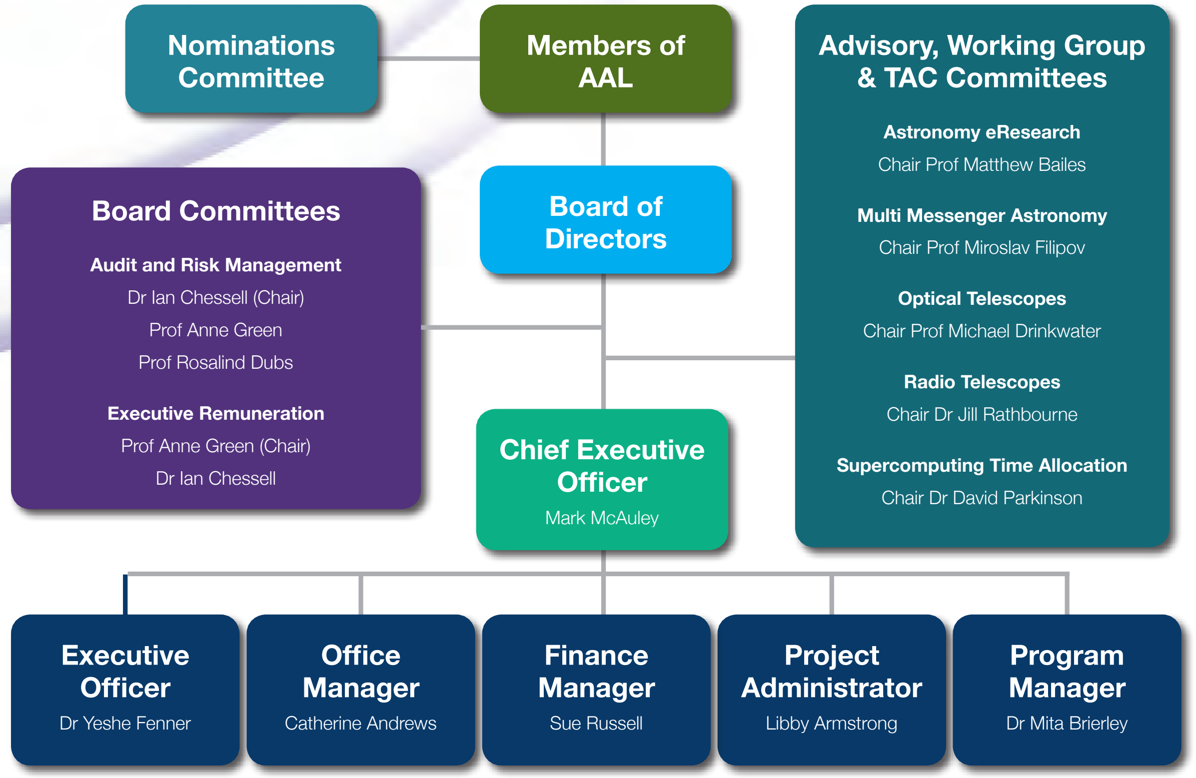
Prof. Brian Boyle is Deputy Vice- Chancellor Research (Acting) and formerly Director of Research Strategy at the University of New South Wales. Previously, he was Acting Australian SKA Director for the Department of Industry, and had roles at CSIRO as SKA Director and Director of the Australia Telescope National Facility (2003-2009) where he initiated the construction of ASKAP. He was also Director of the Anglo Australian Observatory (1996-2003). His main research interests are cosmology, active galactic nuclei and quasars. During his career he has overseen the successful commissioning of world-class instruments and has led many international scientific collaborations. As Chairman of the National Committee for Astronomy, he led the development of the Decadal Plan for Australian Astronomy 2006-15. He was also the facilitator for the NCRIS investment plan for optical and radio astronomy.

Prof. Robyn Owens

BSc(Hons), MSc (Mathematics), PhD (Mathematics), FACS, GAICD, FTSE
Retired AGM 20 November 2015
Special responsibilities: Member of Astronomy eResearch Advisory Committee.

Prof. Robyn Owens is Deputy Vice-Chancellor (Research) at the University of Western Australia (UWA) and has responsibility for research policy development and leadership of the University's research activities, postgraduate education, industry liaison, intellectual property and commercialisation. Previously she was the Head of the School of Computer Science & Software Engineering at UWA and has also lectured in Australia and internationally in mathematics and computer science. She has an extensive background in mathematical analysis and research with a focus on computer vision, including feature detection in images, 3D shape measurement, image understanding, and representation.

Organisational and Governance
Structure



Members:

AAL is very proud that its membership comprises all institutions in Australia with a significant astronomy research program. There are currently 16 institutional members of AAL and each member has a nominated representative who attends the Annual General Meeting to elect Board Directors and Chair. Member representatives are also consulted throughout the year on key astronomy infrastructure and investment decisions.

Committees:

AAL has three advisory committees, one working group, and a supercomputing time allocation committee, whose members are appointed to provide the relevant breadth of expertise, and an appropriate mix of gender, seniority, and institutional diversity. AAL committee members meet quarterly and are encouraged to engage with their colleagues in order to understand and reflect the views of the wider astronomy community. AAL relies on its committee members to monitor and assess the progress of all projects and subprojects, evaluate key performance indicators, and advise on opportunities for collaboration and improving project outcomes.

Board:

The independent, skills-based Board of Directors comprises seven individuals with an appropriate breadth of expertise in astronomy, management and finance. The Board meets quarterly to review progress of programs under AAL's contractual arrangements, set strategic goals, and approve financial allocations. The AAL Board makes key decisions about projects based on the committees' recommendations, the Board's own considerable and diverse expertise, and in consideration of the priorities and recommendations in the Australian Astronomy Decadal Plan.

Staff:

AAL executive and staff have responsibility for financial management, oversight of the programs under AAL's contractual arrangements, reporting to the AAL Board on the status of projects, and liaising with the Advisory Committees, AAL Board, project leaders, Members, Government Departments and other key stakeholders.

These governance and management arrangements have led to very successful outcomes from AAL-managed NCRIS, EIF and other Commonwealth Government's infrastructure programs projects since 2007.

Image: **2016 ASA Conference participants**
Image credit: **ASA, Stephen Blake**

AAL Community Engagement

July

- AAL attended the Women in Astronomy workshop in Brisbane
- AAL sponsored and participated in the Astronomical Society of Australia's Annual Scientific Meeting and launch of the Decadal Plan in Perth

August

- AAL exhibited at the IAU in Hawaii
- AAL attended the launch of the Astronomy Decadal Plan 2016-2025 at Parliament House by the Friends of Science Chair Karen Andrews MP

September

- AAL attended the ACAMAR signing ceremony in China

October

- Publication of AAL's 2014/15 annual report
- AAL attended the ASKAP early science planning workshop in Sydney
- AAL participated in the eResearch Australasia conference in Brisbane
- AAL participated in ADASS, Sydney
- AAL participated in the NCRIS Forum in Canberra
- AAL participated in the IVOA meeting in Sydney

November

- AAL sponsored and participated in Astronomy7, Sydney
- AAL attended GMT groundbreaking in Chile
- AAL's Annual General Meeting at Swinburne University of Technology

December

- AAL's 2014/15 annual report and cover letter sent to the DVC-R or Head of each AAL member institution
- AAL participated in a NeCTAR workshop in Melbourne

February

- AAL attended Global Infrastructure event in Sydney organised by the Department of Education and Training in Canberra

March

- AAL promoted NCRIS at the Universities Australia Higher Education Conference in Canberra
- AAL participated in an AeRO Forum in Canberra
- AAL participated in an NCRIS Forum in Canberra

April

- AAL participated in the ACAMAR workshop in Perth
- AAL attended OzSKA workshop in Perth
- AAL attended a NeCTAR workshop in Melbourne

May

- AAL sponsored the ITSO workshop in Sydney
- AAL Director attended the NCRIS roadmap workshop in Melbourne
- AAL participated in the ASA Early Career Researcher workshop in Victoria

June

- AAL participated in the ASKAP Conference in Sydney

AAL
Members and Committees

Committees

Astronomy eResearch Advisory Committee (AeRAC)

Matthew Bailes (Chair), AAL Board Representative
Simon O'Toole, Australian Astronomical Observatory
Jessica Chapman, CSIRO
Greg Poole, University of Melbourne
Arna Karick, Swinburne University of Technology
Alex Heger, Monash University
Lindsay Botten, NCI Director (ex-officio)
Jarrod Hurley, Swinburne University of Technology Supercomputer Manager (ex-officio)
Jenni Harrison, Pawsey Centre Head of Data (ex-officio)

Computing Infrastructure Planning Working Group (CIPWG)

The Computing Infrastructure Working Group was established in October 2015 comprising all members of AeRAC plus:
Orsola de Marco, Macquaire University
Chris Power, University of Western Australia
Andreas Wicenec, University of Western Australia

Astronomy Supercomputer Time Allocation Committee (ASTAC)

David Parkinson (Chair), University of Queensland
Orsola De Marco, Macquaire University
Randall Wayth, Curtin University
Daniel Mitchell, CSIRO
Christoph Federrath, Australian National University
Chris Power, University of Western Australia
Roger Edberg, NCI Representative (ex-officio)
Chris Harris, Pawsey Representative (ex-officio)
Jarrod Hurley, Swinburne University of Technology, Supercomputer Manager (ex-officio)
Advisors: Roger Edberg, NCI user consultant
Amr Hassan, Swinburne University of Technology, Supercomputer user consultant
Amr Hassan, Secretary, Swinburne University of Technology

Multi Messenger Astronomy Working Group (MMAWG)

Miroslav Filipovic (Chair), University of Western Sydney
Roger Clay, University of Adelaide
Gary Hill, University of Adelaide
Duncan Galloway, Monash University
Gavin Rowell, University of Adelaide
Keith Bannister, CSIRO
Linqing Wen, University of Western Australia
Bram Slagmolen, Australian National University
Ron Ekers, AAL Board Representative (ex-officio)

Optical Telescopes Advisory Committee (OTAC)

Michael Drinkwater (Chair), University of Queensland
Peter Tuthill (Deputy Chair), University of Sydney
Emma Ryan-Weber, Swinburne University of Technology
Martin Asplund, Australian National University
Michele Trenti, University of Melbourne
Michael Ashley, University of New South Wales
Andy Sheinis, Australian Astronomical Observatory
Lisa Kewley, AAL Board representative (ex-officio)
Warrick Couch, Director, Australian Astronomical Observatory (ex-officio)
Stuart Ryder, Head of International Telescopes Support Office (ex-officio)
Gayandhi De Silva, Magellan Science Advisory Committee Representative (ex-officio)

Radio Telescopes Advisory Committee (RTAC)

Jill Rathborne (Chair), CSIRO
Nick Seymour (Deputy Chair), Curtin University
Michael Burton, University of New South Wales
Stuart Ryder, Australian Astronomical Observatory
Simon Ellingsen, University of Tasmania
Naomi McClure-Griffiths, Australian National University
Ian Heywood, CSIRO
Attila Popping, University of Western Australia
Rachel Webster, Astronomy Australia Ltd Board representative (ex-officio)
John Reynolds, Acting Program Director, ATNF Operations, CSIRO (ex-officio)

Members

Member Representative	Member
Australian Astronomical Observatory	Prof Warrick Couch
Australian National University	Prof Matthew Colless
Commonwealth Scientific and Industrial Research Organisation	Dr Douglas Bock
Curtin University	Prof Carole Jackson
Macquarie University	Prof Mark Wardle
Monash University	Prof Alexander Heger
Swinburne University of Technology	Prof Karl Glazebrook
University of Adelaide	A/Prof Gavin Rowell
University of Melbourne	Dr Christian Reichardt
University of New South Wales	Prof Jeremy Bailey
University of Queensland	Prof Michael Drinkwater
University of Southern Queensland	Prof Brad Carter
University of Sydney	Prof Joss Bland-Hawthorn
University of Tasmania	Prof John Dickey
University of Western Australia	Prof Peter Quinn
University of Western Sydney	Prof Miroslav Filipovic

Optical Telescopes Representatives

Giant Magellan Telescope

Board: Nigel Poole, University of New South Wales
GMTO Founder Representative: Mark McAuley, AAL
Science Advisory Committee: Prof Chris Tinney, University of New South Wales

Magellan

Magellan Council : Prof Brian Boyle, University of New South Wales (observer)
Magellan SAC: Prof Gayandhi De Silva, The University of Sydney (observer)

Gemini

Board: Prof Stuart Wyithe, University of Melbourne
Finance Committee: Prof Stuart Wyithe, University of Melbourne
Science Advisory Committee: Dr Sarah Martell, University of New South Wales

Keck

CARA Board: Lisa Kewley, Australian National University, (ANU appointment)

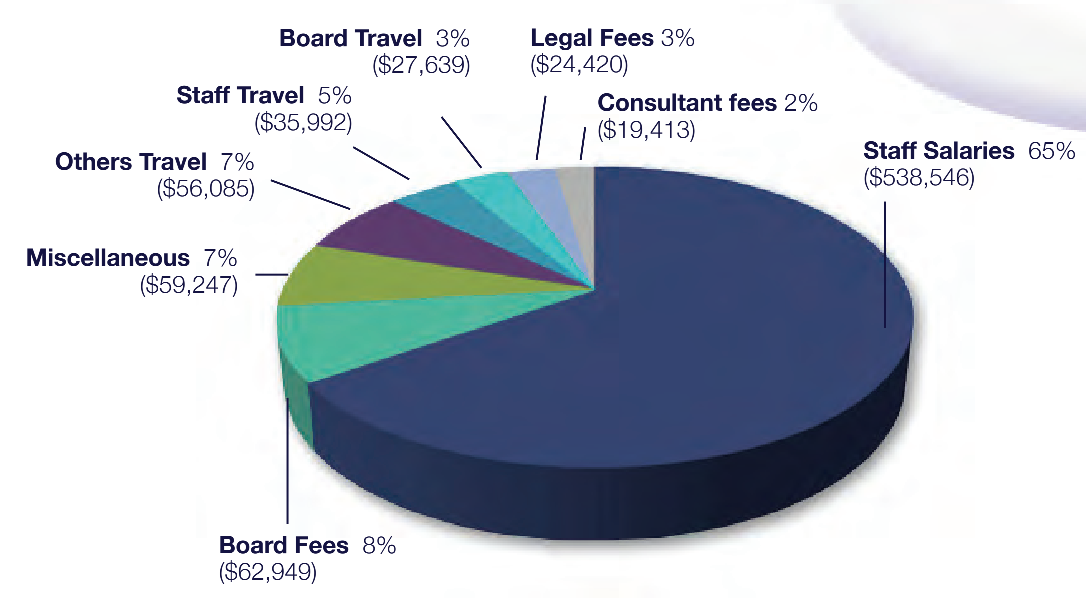
All Members, their representatives and committee members are accurate as of 30th June 2016.

Financial Summary

The following summary highlights the key financial transactions (exclusive of GST) for the 2015/16 financial year. The audited financial accounts are available on the AAL website at: http://www.astronomyaustralia.org.au/publications

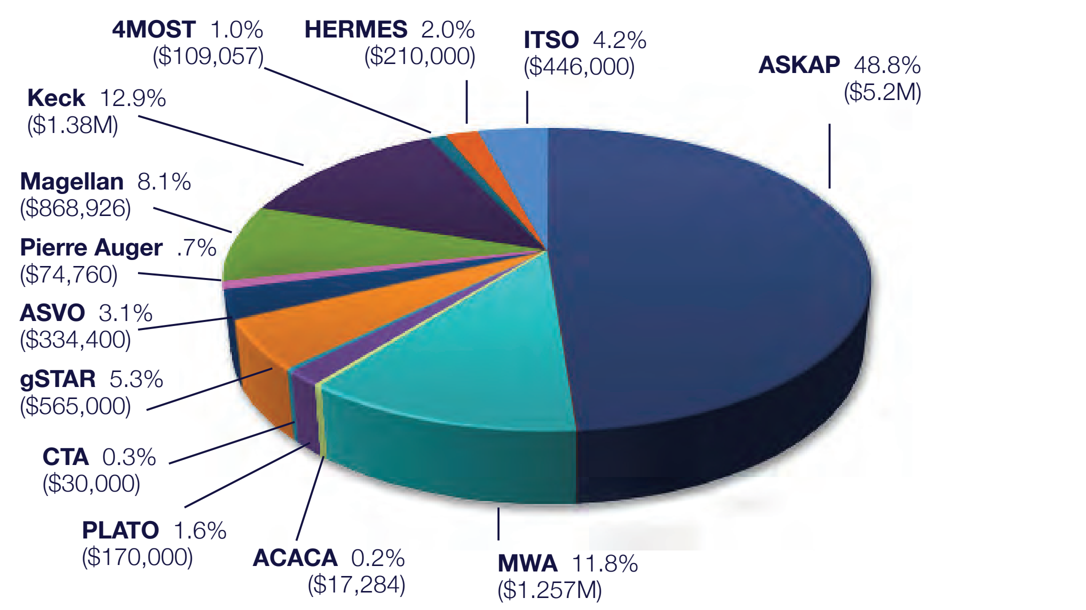
AAL Operating Expenses

Actual operating expenses for 2015/16 were $824,291.



Grants Paid to Projects during 2015/16

Total grants paid in 2015/16 were $10,662,738.



Grants Received and Balance of Grants held as at 30 June 2016

Grant	Grants Received	Closing Balance
NCRIS 2013 Grant	-	$1,232,875
AAO 2014 Grant	-	$290,000
ANDS Grant	$15,000	-
NeCTAR NCRIS Grant	$136,400	$12,500
DoIIS 2015 Grant	-	$1,531,620
NCRIS 2015 Grant	$8,644,000	$801,986
DoIIS 2016 Grant	$1,750,000	$1,750,000
NCRIS 2016 Grant	$1,411,327	$1,411,327
	$11,956,727	**$7,030,308**

Reserves

During 2015/16 AAL maintained two reserves with the net interest earned to be used for projects associated with the relevant funding agreement. There were the following transfers to and from Reserves:

Reserve	Net Interest	Transfer from Reserve	Purpose of Funds	Closing Balance
Overseas Optical Reserve*	$62,914	$53,137 $58,072	AAL management fee Shortfall in Magellan payment	$2,608,579[#]
NCRIS 2013-15 Reserve	$107,382	-		$143,669[##]

*The Overseas Optical Reserve is primarily used to cover shortfalls in payments to overseas optical telescope facilities.

[#] $101,395 of Overseas Optical Reserve is committed for future Magellan payments.
[##] $33,748 of NCRIS 2013-15 Reserve is committed for the gSTAR Data Platform project.

Statement of profit or loss and other comprehensive income for the year ended 30 June 2016

	2016 $	2015 $
Revenue including Government Grants	11,577,784	8,970,548
Expenses		
Depreciation	(2,581)	(1,698)
Grants paid	(10,633,681)	(8,072,689)
Direct grant project expenses	(29,265)	(4,223)
Employee benefits expenses	(601,494)	(539,017)
Other expenses	(220,216)	(237,910)
Surplus (Deficit) before income tax attributable to members of the entity	**90,547**	**115,011**
Income tax	-	-
Surplus (Deficit) after income tax attributable to members of Astronomy Australia Ltd	**90,547**	**115,011**
Other comprehensive income	-	-
Total comprehensive income for the year attributable to members of Astronomy Australia Ltd	**90,547**	**115,011**

The Company is an income tax exempt charitable institution.

Statement of changes in equity for the year ended 30 June 2016

	Retained Surpluses $	Overseas Optical Reserve Account $	NCRIS2013-2015 Reserve Account $	Total Equity $
Balance at 30 June 2014	**245,127**	**2,639,737**	**23,275**	**2,908,139**
Surplus attributable to equity members	115,011	-	-	115,011
Allocated to Reserves	(82,944)	69,932	13,012	-
Transfers from Reserves	52,795	(52,795)	-	-
Balance at 30 June 2015	**329,989**	**2,656,874**	**36,287**	**3,023,150**
Surplus attributable to equity members	90,547	-	-	90,547
Transfer to Reserves	(170,296)	62,914	107,382	-
Allocation from Reserves	111,209	(111,209)	-	-
Balance at 30 June 2016	**361,449**	**2,608,579**	**143,669**	**3,113,697**

Statement of Financial Position as at 30 June 2016

	2016 $	2015 $
Current Assets		
Cash and cash equivalents	10,990,676	9,892,249
Trade and other receivables	-	6,810
Total Current Assets	10,990,676	9,899,059
Non-Current Assets		
Property, plant and equipment	6,904	2,468
Total Non-Current Assets	6,904	2,468
Total Assets	10,997,580	9,901,527
Current Liabilities		
Trade and other payables	7,833,054	6,838,336
Employee benefits	48,289	40,041
Total Current Liabilities	7,881,343	6,878,377
Non-Current Liabilities		
Employee Benefits	2,540	-
Total Non-Current Liabilities	2,540	-
Total Liabilities	7,883,883	6,878,377
Net Assets	3,113,697	3,023,150
Equity		
Reserves	2,752,248	2,693,161
Retained surpluses	361,449	329,989
Total Equity	3,113,697	3,023,150

The complete audited financial accounts are available on the AAL website at:
http://astronomyaustralia.org.au/publications

Acronyms used in this report

2dF	Two Degree Field
AAL	Astronomy Australia Limited
AAO	Australian Astronomical Observatory
AAT	Anglo-Australian Telescope
ACACA	Australia-China Astronomy Collaboration Award
ACES	ASKAP Commissioning and Early Science
AeRAC	Astronomy eResearch Advisory Committee
AGUSS	Australian Gemini Undergraduate Summer Studentship
AITC	Advanced Instrumentation and Technology Centre
ALMA	Atacama Large Millimeter/submillimeter Array
ANDS	Australian National Data Service
ANU	The Australian National University
ARC	Australian Research Council
ASA	The Astronomical Society of Australia
ASKAP	Australian Square Kilometre Array Pathfinder
ASTAC	Astronomy Supercomputer Time Allocation Committee
AST3	Antarctic Survey Telescopes
ASVO	All-Sky Virtual Observatory
ATCA	Australia Telescope Compact Array
ATNF	Australia Telescope National Facility
AURA	Association of Universities for Research in Astronomy
AusGO	Australian Gemini Office
BETA	Boolardy Engineering Test Array
CAASTRO	ARC Centre of Excellence for All-sky Astrophysics
CASS	CSIRO Astronomy and Space Science
CCD	Charge-coupled device
CIIC	Cisco Internet of Everything Innovation Centre
CIPWG	Computing Infrastructure Planning Working Group
CPU	Central Processing Unit
CRIS	Collaborative Research Infrastructure Strategy
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTA	Cherenkov Telescope Array
CUDA	Compute Unified Device Architecture
DIICCSRTE	Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education
DoIS	Department of Industry and Science
DVC-R	Deputy Vice-Chancellor, Research
EIF	Education Investment Fund
ELT	Extremely Large Telescope
EoR	Epoch of Reionization
ESO	European Southern Observatory
FAA	Fellow of the Australian Academy of Science
FAICD	Fellow of the Australian Institute of Company Directors
FAIP	Fellow of the Australian Institute of Physics
FASA	Fellow of the Astronomical Society of Australia
FAST	Five Hundred Meter Aperture Spherical Telescope
FIEAust	Fellow of the Institution of Engineers Australia
FIEChem	E Fellow of the Institution of Chemical Engineers
FRACI	Fellow of the Royal Australian Chemical Institute
FRAS	Fellow of the Royal Astronomical Society
FRB	Fast Radio Burst
FTE	Full time equivalent
FTSE	Fellow of the Australian Academy of Technological and Engineering Sciences
GALAH	GALactic Archaeology with HERMES
GAMA	Galaxy And Mass Assembly
GMACS	GMT Wide-Field Optical Spectrograph
GMT	Giant Magellan Telescope
GMTIFS	GMT Integral Field Spectrograph
GMTO	Giant Magellan Telescope Organization
GPU	Graphics Processing Unit
GST	Goods and Services Tax
gSTAR	GPU Supercomputer for Theoretical Astrophysics Research
HEAT	High Elevation Antarctic Terahertz (telescope)
HERMES	High Efficiency and Resolution Multi-Element Spectrograph
HPC	High Performance Computing
ICRAR	International Centre for Radio Astronomy Research
ITSO	International Telescope Support Office
KTAC	Keck Time Allocation Committee
MANIFEST	MANy-Instrument FibrE SysTem
MMAAC	Multi Messenger Astronomy Advisory Committee
MMAWG	Multi Messenger Astronomy Working Group
MRO	Murchison Radio-astronomy Observatory
MWA	Murchison Widefield Array
NCA	National Committee for Astronomy
NCI	National Computational Infrastructure
NCRIS	National Collaborative Research Infrastructure Strategy
NeCTAR	National eResearch Collaboration Tools and Resources
NIRMOS	Near Infrared Multi-Object Spectrograph
NIRSPEC	Near Infrared Spectrograph
NISM	Near Infrared Spectrograph Monitor
LTAO	Laser Tomography Adaptive Optics
OOR	Overseas Optical Reserve
OTAC	Optical Telescopes Advisory Committee
OzDES	Australian Dark Energy Survey
PAF	Phased Array Feed
PLATO	Plateau Observatory
PRIC	Polar Research Institute of China
RDS	Research Data Services
RTAC	Radio Telescopes Advisory Committee
SAMI	Sydney-AAO Multi-object Integral-field
SKA	Square Kilometre Array
SME	Small and Medium Enterprise
STAC	Science and Technology Advisory Committee
SUPERB	Survey for Pulsars and Extragalactic Radio Bursts
swinSTAR	Swinburne Supercomputer for Theoretical Academic Research
TAC	Time Allocation Committee
TAO	Theoretical Astrophysical Observatory
UNSW	University of New South Wales
UWA	University of Western Australia
UWS	University of Western Sydney

Astronomy Australia Ltd.

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NCRIS
National Research Infrastructure for Australia
An Australian Government Initiative

Astronomy Australia Ltd

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