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Spreading across the continent: the Astronomical Society of Australia 1966–2023

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ABSTRACT

Australian astronomy has undergone huge changes since the middle of the twentieth century, when astronomers generally only had access to the observing facilities of their own institution. In this paper, we look at the changes in the context of the membership of the Astronomical Society of Australia (ASA), since its formation in 1966. Initially, the dominant institutions were the Australian National University, the University of Sydney and the CSIRO, with each of these having more than twice the members of any other Australian institution. Access to world-class national facilities provided by the Anglo-Australian Telescope (AAT, an optical telescope) from 1975 and the Australia Telescope Compact Array (ATCA, a radio telescope) from 1991, led to increases in astronomer numbers at institutions other than the three dominant ones. More recently, to stay internationally competitive, astronomers need access to even larger observing facilities. One of these facilities is the Square Kilometre Array project (SKA). This radio telescope is to be split between Southern Africa and Australia with SKA-Low, observing in low frequency radio waves, to be sited at a remote location in Western Australia. That plan, and two new SKA precursor instruments, has boosted the number of astronomers in the state, making Western Australia one of the major centres of astrophysical research in Australia.

Keywords: Australia Telescope Compact Array, centres of excellence in astronomy, European Southern Observatory, history of Australian astronomy, International Centre for Radio Astronomy Research, SKA-Low, the Anglo-Australian Telescope, the Astronomical Society of Australia, the Australia Telescope, the Square Kilometre Array.

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Introduction

Astronomy has changed since the formation of the Astronomical Society of Australia (ASA) in late 1966.[1] At that time Australian astronomers were concentrated at a limited number of institutions, mainly in Sydney and Canberra, as discussed in the following section. The institutions were universities, such as the University of Sydney and the Australian National University, CSIRO Radiophysics and the older (optical) state observatories at Sydney and Perth. Astronomers worked on their own or in small teams with their immediate colleagues and generally made observations with their institutions' own telescopes and facilities. They were a fairly homogeneous group consisting mainly of white men, with very few women, who made up only eleven out of the 255 members in the 1969 members list.[2]

Technology was comparatively basic with optical telescopes that were much smaller than the major ones today. The largest telescope in the country was the 74-inch[3] diameter reflector at Mount Stromlo Observatory. That, and every other telescope in the country, was guided by hand, that is, without computer control. Observations were

[1] Lomb (2015).
[2] Astronomical Society of Australia (1969).
[3] 1.9-m.

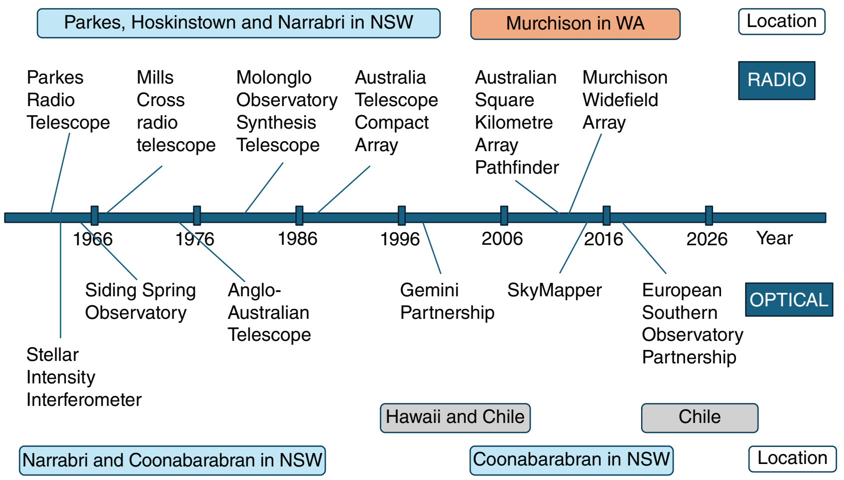

Fig. 1. Some of the main radio and optical instruments available to Australian astronomers, on a timeline divided into decadal intervals from the formation of the ASA in 1966. The location of each instrument is indicated above the radio wavelength instruments and below the optical ones. Blue highlights NSW instruments, orange Western Australian and grey overseas.

only of single objects, with records made using photographic glass plates or photoelectric photometers.

Today, the picture is quite different. Astronomers have spread across the continent, with a large concentration in Western Australia. The Northern Territory is the only part of Australia without ASA members, as none of its three tertiary institutions conducts research in the field.[4] For major projects, astronomers work together in large groups with collaborators from a variety of Australian and international institutions. Observations are made with national and international instruments, including space telescopes. For optical astronomy, these observations are made with highly sensitive electronic imagers and spectrographs that often record hundreds of objects at a time. Diversity among ASA members has greatly increased (though there are signs it could still increase further), with more women astronomers and more astronomers with diverse backgrounds.

Fig. 1 shows a timeline of some of the main radio and optical instruments available to Australian astronomers. In this paper we consider the impact of these and other instruments and developments on members of the ASA. We provide a snapshot of astronomy in Australia in decadal intervals (the same as shown in Fig. 1) and consider from which institutions ASA members came from in each of those epochs. We look at the main astronomical topics being examined at those institutions, the observational facilities available and the size of collaborations. Examples of these are taken, where possible from the *Publications* (originally *Proceedings*) *of the Astronomical Society of Australia*.

The discussion of these changes is not meant as a comprehensive history of Australian astronomy, with many institutions and important research projects and fields not covered. Instead, we look at the relevant factors that may have affected where astronomers were based, including the trends in the location of new instruments evident in Fig. 1. In particular, we consider if, as seems probable, that it was the availability of observing facilities, including national facilities, that had the greatest impact.

This paper is the fifth in a series on the history of the ASA. The first discussed the formation of the ASA, the second its journal, the *Publications of the Astronomical Society of Australia*, while the third and fourth were about the two general assemblies of the International Astronomical Union (IAU) held in Australia in 1973 and in 2003, in the organisation of both of which the ASA was closely involved.[5] This current work has a companion paper, in which we consider the changes in the diversity of astronomers working in Australia, including male/female ratios, since the formation of the ASA in 1966.[6] As well, we examine the experiences of Australian women astronomers and those of people from marginalised groups in astronomy.

1966–75: three major institutions

In the 1969 membership list,[7] the Astronomical Society of Australia had 255 individual members. In addition, a number of companies had joined as corporate members, but these are not discussed here. Three institutions stand out in the list as hosting large numbers of members: CSIRO, mainly Radiophysics, with sixty members; the University of Sydney, mainly the School of Physics, with forty-nine members; and the Australian National University, mainly from Mount Stromlo and Siding Spring Observatories, with forty-three members. The only other institutions with more than ten members were the University of Adelaide with

[4]Northern Territory PHN (2023).
[5]Lomb (2015, 2018, 2020*a*, 2020*b*).
[6]T. Stevenson and N. Lomb, unpubl. data.
[7]Astronomical Society of Australia (1969).

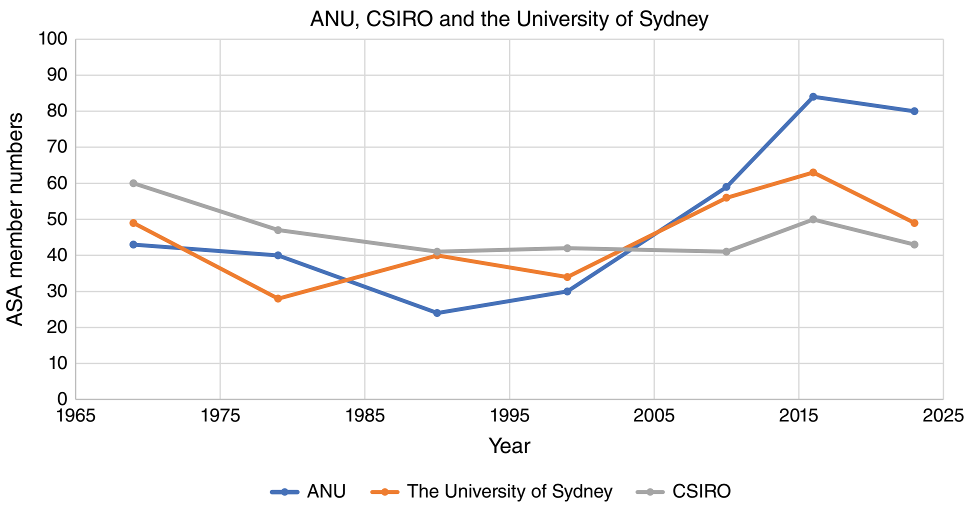

Fig. 2. The number of non-corporate ASA members since the formation of the society at the Australian National University, CSIRO and the University of Sydney.

eighteen and the University of Tasmania with twelve. Fig. 2 shows the numbers for the three dominant institutions, and we can see that they have maintained or increased these high numbers up to the present day. In particular, the numbers at the Australian National University have almost doubled from 1969 to 2023, with student numbers increasing proportionally.

These three institutions are discussed below. Importantly, unlike other institutions, each had its own high-quality research facilities available for the use of their staff and research students. The rest of the society's members were scattered around the country, mostly in universities. Apart from the two universities mentioned above, the only others with member numbers in double figures were Adelaide and Tasmania. There were also members overseas, mainly in the USA. These were likely to be Australians who have moved overseas, temporarily or permanently, or foreign scientists who had spent time in Australia. They were counted in the total ASA numbers but not when analysing membership at individual institutions.

CSIRO

In the 1960s, CSIRO Radiophysics had concentrated its research around two instruments: the 64-m Parkes Radio Telescope[8] and the Radioheliograph, which is shown in Fig. 3. The former had been inaugurated in October 1961,[9] while the latter instrument, designed to make rapid two-dimensional images of the Sun at 80 MHz, was at least partially operating by 1967.[10]

The main project of the Parkes telescope was to compile a catalogue of radio sources at 408 MHz with high accuracy to allow optical identifications.[11] Later this was repeated at a higher frequency of 2700 MHz,[12] and thousands of new Parkes sources were added. Many of these were found to be quasars.[13] Other scientific projects at Parkes were the study of pulsars, after their discovery in 1968, searching for interstellar molecules and observations of interstellar hydrogen, especially from the Large and Small Magellanic Clouds.[14] The last project led to Don Mathewson's discovery of the Magellanic Stream.[15] The most famous activity of the Parkes telescope during the period was receiving the TV transmission of the first footsteps on the Moon in 1969 and relaying the signal world-wide.[16]

University of Sydney

At the University of Sydney, there were astronomers at a number of places. The main concentration was in the School of Physics, headed by Harry Messel (1922–2015), that had a Department of Astrophysics and a Department of Astronomy.[17] The first of these was involved in radio astronomy using its own Mills Cross telescope that had been inaugurated in 1965 and become operational in 1967. Devised by the head of the department, Bernard Yarnton (Bernie) Mills (1920–2011), this cross-shaped telescope,

[8]Since 2020 the telescope also has the Wiradjuri name of *Murriyang*.
[9]Robertson (1992) p. 182.
[10]Wild (1967).
[11]Robertson (1992) pp. 243–244. Shimmins (1967).
[12]Wall and others (1971).
[13]Peterson and Bolton (1973).
[14]Robertson (1992) pp. 303–335.
[15]Mathewson (1976).
[16]Sarkissian (2001).
[17]McCaughan (1987).

Fig. 3. Some of the antennas of the Radioheliograph in 1968. Image credit: CSIRO Radio Astronomy Image Archive.

with its two arms each a mile (1.6 km) long, was situated at Hoskinstown near Canberra and the Molonglo River. After the discovery of pulsars, the Mills Cross became an efficient instrument for finding them.[18] A significant discovery was that of the Vela pulsar, the first to be associated with a supernova remnant. The telescope's main role, however, was the survey of extended radio sources in the sky.[19]

Robert Hanbury Brown (1916–2002) headed the astronomy department: it was devoted to the use of the Stellar Intensity Interferometer that had been completed at Narrabri in 1963.[20] The optical interferometer consisted of two giant 6.7-m diameter mirrors, each a mosaic made up of 252 identical hexagonal pieces that collected light, but could not form sharp images. The mirrors moved on a 188-m diameter circular railway track that allowed them to operate as an interferometric pair, the baseline orientation and spacing of which could be changed. The main aim of the instrument was to measure the angular sizes of early type stars; the effective temperature of each star could then be determined to high accuracy by combining the angular size with its measured flux.[21] The project ended in 1972 with the angular diameter of thirty-two stars measured. There was also an optical astronomer in the department, Robert Reginald (Bob) Shobbrook (1937–2014), who was originally going to be involved in the optical identification of radio sources in the Molonglo Catalogue, but he became increasingly absorbed in the observation of variable stars.[22]

There were also thirteen ASA members at the university's School of Electrical Engineering that operated a radio telescope at Badgery's Creek, just outside Sydney. The original telescope had belonged to CSIRO Radiophysics, but after its developer, Wilbur Norman (Chris) Christiansen (1913–2007), accepted the position of professor of electrical engineering, the telescope and its site were transferred to the university.[23] The original telescope consisted of thirty-two dishes, each of 5.8-m diameter, spread over an east-west and a north-south arm. At the university, Christiansen slowly upgraded the instrument, so that by the early 1970s it became the Fleurs Synthesis Telescope with the addition of six new 13.7-m diameter dishes.[24] Research encompassed large radio galaxies, supernova remnants and emission nebulae, as well as making daily 21 cm maps of the Sun.[25] The Applied Mathematics Department, with four ASA members, also engaged in theoretical work on the Sun.[26]

Australian National University

At the Australian National University's Mount Stromlo Observatory, a new director, Olin Jeuck Eggen (1919–98), took up his appointment on 1 July 1966.[27] With the help of some new staff appointments, Eggen greatly increased the observatory's scientific output: during his time the average number of refereed papers published each year doubled from what it was previously. When he took over, the main instrument at Stromlo was the 74-inch reflector that had been officially opened in 1955. As well, there was a field station at Siding Spring Mountain, near Coonabarabran, with three new optical telescopes, including a 40-inch[28] reflector. Eggen incorporated the field station into the name of the institution, which became Mount Stromlo and Siding Spring Observatories.

Eggen himself often used the 40-inch for photoelectric brightness observations that were an essential part of his study of the three-dimensional motions of stars in the Milky Way galaxy.[29] Other research included that of Ken Freeman

[18] Mills (1969).
[19] Large and others (1981).
[20] McCaughan (1987).
[21] Brown (1967).
[22] Shobbrook and others (1972).
[23] Orchiston and others (2021) pp. 205–249.
[24] Christiansen (1972).
[25] Orchiston and others (2021) pp. 205–249.
[26] Wilson (1972).
[27] Frame and Faulkner (2003).
[28] 1.0-m.
[29] Eggen (1971).

on the motions of stars and their mass distribution in external galaxies.[30] Some of their colleagues were involved in making estimates of the chemical compositions of stars with the help of digital models of stellar atmospheres. Another project was the identification of radio sources that had been found with CSIRO's Parkes Radio Telescope. John Gatenby Bolton (1922–1993), the director at Parkes, collaborated with Bruce Peterson at Mount Stromlo to photograph possible quasars[31] with an image tube camera on the 74-inch telescope.[32]

During that period, planning and construction began on the 3.9-m Anglo-Australian Telescope, that was to be much larger than any other optical telescope in Australia. Mount Stromlo, led by Eggen. engaged in a major dispute with other Australian astronomers regarding the management of the telescope that was to be sited at Siding Spring.[33] Eggen wanted Mount Stromlo to be wholly in charge of the telescope, instead of it having an independent structure. Stromlo lost the argument, an argument that led to lingering ill-feeling between Stromlo and other groups, especially the new Anglo-Australian Observatory.

1976–85: the Anglo-Australian telescope

In this period, the CSIRO, the Australian National University and the University of Sydney remained the dominant astronomical institutions in Australia, as shown in Fig. 2. They were followed by the University of Tasmania and Monash University. It is worth noting that there were only five members from Western Australia, based at Perth Observatory and at Learmonth Solar Observatory, while there was only one member at the University of Queensland, the sole member in the state.

A major change in Australian astronomy occurred with the building of the Anglo-Australian Telescope (AAT), by the British and Australian governments (Fig. 4). The 3.9-m aperture optical telescope that began regularly scheduled operations on 28 June 1975,[34] was a game changer for Australian astronomy, as it was designated as a national facility.[35] This enabled astronomers at smaller institutions, without their own telescopes, to gain access to a world-class instrument through a competitive application process. For Australian astronomers, this process was managed by the Australian Time Assignment Committee (ATAC).

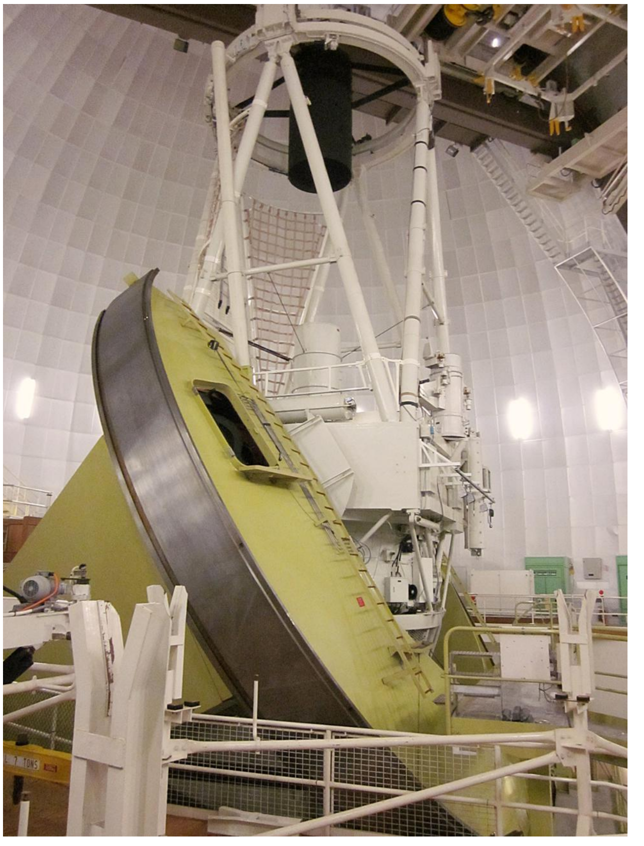

Fig. 4. The Anglo-Australian Telescope at Siding Spring Observatory in September 2012. Photo: Nick Lomb.

The AAT was operated by the newly established Anglo-Australian Observatory that, as shown in Fig. 5, only had five ASA members. A relatively low number of staff astronomers was needed at the observatory, as visiting astronomers used much of the observing time on the telescope, but a large team of engineers and technicians was necessary to support the telescope and its suite of high-quality instruments. Two early digital imaging instruments for the telescope were the Image Dissector Scanner, used with a low dispersion spectrograph, and the Image Photon Counting System, used with a spectrograph that allowed higher resolutions.[36] The latter instrument is now part of the collection of the Powerhouse Museum, Sydney.[37] Another important instrument, developed by staff astronomer David Allen (1946–94), was the

[30] Freeman (1970).
[31] Then called QSOs.
[32] Peterson and Bolton (1973).
[33] Gascoigne and others (1990) pp. 125–147.
[34] Morton (1977).
[35] Gascoigne and others (1990) p. 243.
[36] Bessell (2011).
[37] Powerhouse (*n.d.*).

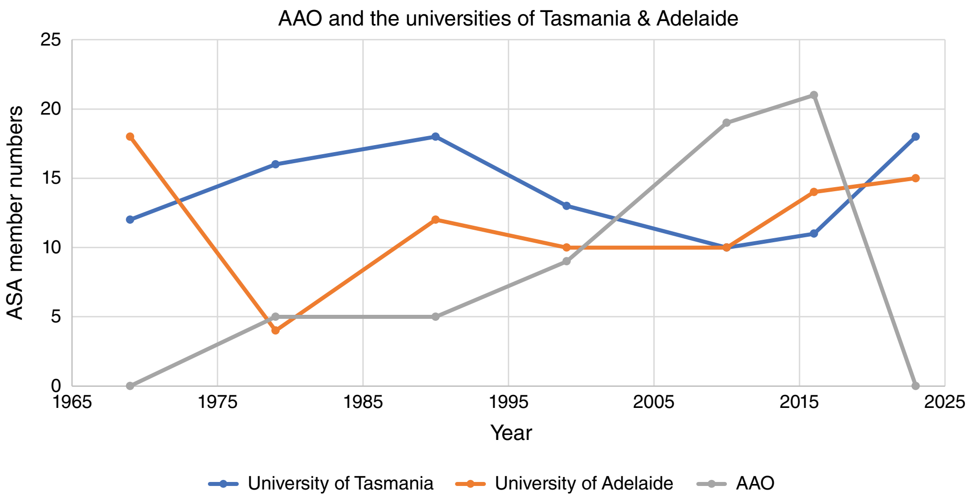

Fig. 5. The number of non-corporate ASA members since the formation of the society at the Anglo-Australian Observatory, the University of Tasmania and the University of Adelaide.

Infrared Photometer-Spectrometer (IRPS).[38] The AAT was also a world leader in utilising fibre optics to allow spectroscopy of multiple objects simultaneously.[39] A system called Fibre Optics Coupled Aperture Plates (FOCAP) was developed that involved pre-drilled brass plates custom made for each sky field.

An early observation established the reputation of the telescope. This was the discovery of optical pulses from the Vela (radio) pulsar,[40] only the second detection of pulses from a pulsar after that from the Crab Nebula. The profile of the telescope was further boosted by a series of colour images taken by staff photographer David Malin.[41] These were based on the combination of three monochrome photographic plates exposed through three different colour filters and provided the first deep colour images of celestial objects.

At the University of Sydney, the Mills Cross radio telescope was upgraded using only the East and West arms, but with the addition of a slow tilt drive.[42] This allowed the telescope to observe an area of the sky for 12 h and synthesise an image with high sensitivity. The new Molonglo Observatory Synthesis Telescope (MOST) began its observing program in July 1981, with a radio source mapped at 43-arcsecond resolution over a 23-arcminute field. Alec Little (1925–85) was its first director, while later long-serving directors were Anne Green, the president of the ASA in 2003 and 2004, and Richard (Dick) Hunstead (1943–2020).

1986–95: radio telescopes and a new national facility

In the 1980s, the University of Tasmania had one of the larger groups in Australian astronomy with ten members of the ASA. Fig. 5 shows that, with some ups and downs, its member numbers remained steady over the following decades. The university was one of the three organisations in Australia conducting radio astronomy research with its own facilities. Thanks to Grote Reber (1911–2002), who had built the first steerable radio telescope, and Graeme (Bill) Ellis (1921–2011), professor of physics, the University of Tasmania had a long history of observing low frequency radio waves.[43] In 1985, the university's radio astronomers joined the mainstream with the acquisition of a 26-m steerable radio telescope that had been previously used for satellite tracking at Orroral Valley near Canberra.[44] The university sited this on Mt Pleasant, approximately 20 km east of Hobart. Observations with the telescope were at higher frequencies; one study with the telescope, based on observations in 1992 and 1993, was a survey of maser emission at 6.7 GHz in an area of the galactic plane.[45]

In the previous decade, the country's optical astronomy had been greatly boosted through the availability of the world-class 3.9-m Anglo-Australian Telescope (AAT). The construction of what was initially called the Australia Telescope provided a similar effect for radio astronomers. The telescope had been a Bicentennial Project and was opened by Prime Minister Bob Hawke on 2 September,

[38]Storey (2011).
[39]Gray (2011).
[40]Manchester and others (1978). Wallace and others (1977).
[41]Morton (1983).
[42]McAdam (2008).
[43]George and others (2015).
[44]University of Tasmania (2021).
[45]Ellingsen and others (1996).

Fig. 6. The opening of the Australia Telescope in 1988. Photo: Nick Lomb.

during the bicentennial year of 1988 (Fig. 6). Its core is the Australia Telescope Compact Array (ATCA), which is a collection of six 22-m parabolic dishes, with five of them able to be moved along a 3-km long railway track.[46] They are situated at Narrabri, at the former site of the Radioheliograph that had been previously closed down. The compact array can function as a synthesis telescope on its own or, when used together with the Parkes Radio Telescope and a specially constructed 22-m parabolic dish near Coonabarabran, it can form the Australia Telescope.

The array began to function as a national facility in April 1991 but it was in demand prior to this date: in the first eleven months of 1991 observing time was allocated to eighty projects.[47] Australian astronomers outside the ATNF (Australia Telescope National Facility, the new name of CSIRO Radiophysics), were associated with 64% of these and overseas astronomers with 40%. In 1992, the compact array was being used by twelve Australian institutions and twenty-eight from overseas; observers included thirty-seven PhD students. An important early project with the compact array was the observation of the radio emission from supernova SN 1987A that had been discovered visually in February 1987. Once the full 6 km length of the compact array became available, its 0.85-arcsecond resolution allowed the source of the radio emission from the supernova to be resolved and its position identified for the first time.

SN1987A was the first naked eye supernova in 400 years and created great excitement for Australian astronomers, since it was only visible from the southern hemisphere. The AAT was extensively used to observe the supernova, even if that meant that previously assigned observing times to astronomers had to be overridden.[48] New equipment was rapidly assembled, many innovative observations were made, and David Malin's combined image of the supernova and its pre-explosion image was widely distributed.

Another new instrument during the decade was the Sydney University Stellar Interferometer (SUSI). This was the successor to Hanbury Brown's Stellar Intensity Interferometer and similarly located near Narrabri, NSW. SUSI, which was in the commissioning phase in 1992, was a two beam interferometer with siderostat mirrors of 20-cm aperture reflecting the light beams into a central laboratory.[49] It had baselines ranging between 5 and 160 m and measured the diameter of hot stars up to a limiting magnitude of approximately 6.5.

1996–2005: going international

From the 1990s onwards, Australia signed up to contribute to and take part in a number of major international projects, as the country's existing astronomical facilities were no longer fully competitive. Access to these international projects enabled a rapid expansion of astronomical research, and hence the number of astronomers and ASA members in the following decade (Fig. 7), as will be discussed in the next section.

In May 1998, Australia became part of the Gemini Partnership that was developing two 8-m aperture telescopes, one on Mauna Kea, Hawaii, and the other on Cerro Pachon, Chile.[50] The latter telescope, Gemini South, reached first light in 2000, by which time Gemini North was already making scientific observations. Australian astronomers were guaranteed just under five percent of the time on the two telescopes. Being in the partnership, not only provided telescope time, but also allowed proposing and building instruments for the telescopes. The first example of such an instrument was the Near-infrared Integral Field Spectrograph (NIFS) built by the Australian National University's Research School of Astronomy and Astrophysics, with its headquarters at Mount Stromlo Observatory.[51] This instrument performs near-diffraction-limited, near-infrared, imaging spectroscopy using Gemini North.

Another international project is the Square Kilometre Array (SKA), a radio telescope that is planned to be 100 times more sensitive than any previous radio telescope. On 10 August 2000, Australia signed a memorandum of understanding to become one of eleven countries setting up a steering committee for the SKA.[52] It was hoped that the telescope would be sited in the country and a location in

[46] Frater and others (1992).
[47] Ekers and Whiteoak (1992).
[48] Cannon (2011).
[49] Robertson and others (2010).
[50] National Committee for Astronomy of the Australian Academy of Science (2001) pp. 18–19.
[51] McGregor and others (2001).
[52] Ekers (2012).

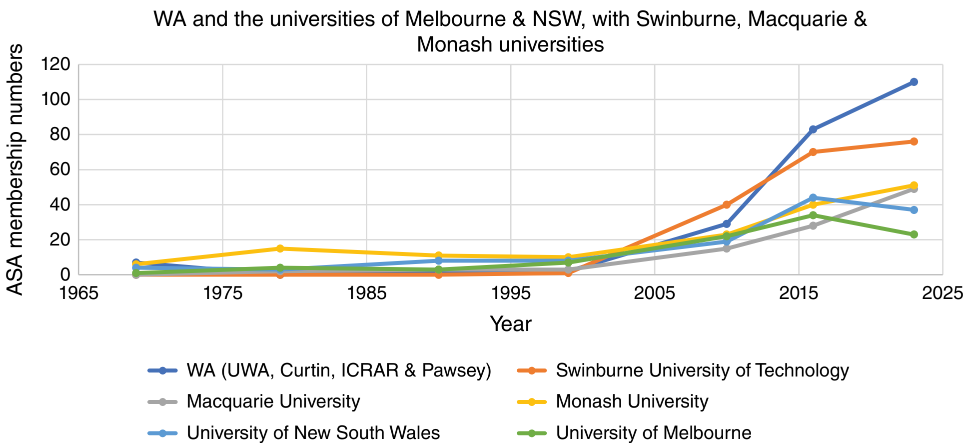

Fig. 7. The number of non-corporate ASA members since the formation of the society in Western Australia (the University of Western Australia, ICRAR and the Pawsey Centre), and at the universities of Melbourne and New South Wales, plus Swinburne, Macquarie and Monash universities.

Western Australia was selected as a possible site. As discussed in the next section, this provided a large impetus to radio astronomy in Western Australia and an expansion in the numbers of astronomers, and hence ASA members, working there (Fig. 7). Although, at a later stage of development, the SKA was split into two—SKA-Low in Australia and SKA-Mid in Southern Africa—this has not disrupted the work in the state.[53]

A further international project sited in Australia was CANGAROO II. This was a joint project between the University of Tokyo, the University of Adelaide and the Australian National University.[54] Gamma rays of energy 100 GeV to 20 TeV were observed using a 10-m mirror telescope located at Woomera, South Australia. One project with the telescope was to search for gamma ray emission from active galactic nuclei (AGN).[55] Out of the eight AGNs observed, emission was seen from one in the energy range above 9.3 TeV. The University of Adelaide also takes part in other international projects, including the Pierre Auger Observatory, the world's largest cosmic ray detector.[56] Cosmic ray studies are also conducted elsewhere, notably at the University of Tasmania, in conjunction with the Australian Antarctic Division. One of their facilities is at the Australian Mawson Base in Antarctica and looks for anisotropies in cosmic rays.[57] Fig. 5 shows ASA membership numbers at the universities of Tasmania and Adelaide.

Upgrades to existing Australian facilities were also carried out during the decade. One of these upgrades was that of the Australia Telescope's compact array that was upgraded to allow millimetre wavelength astronomy.[58] This allows the compact array to observe phenomena such as molecular lines, molecular clouds, star formation and molecular gas in the centre of the galaxy. Until the completion of the Atacama Large Millimeter Array (ALMA) sited in Chile in 2011, it provided the only millimetre array in the southern hemisphere.

Another upgrade was to the 3.9-m Anglo-Australian Telescope. This was the completion of the 2dF instrument that allowed the measurement of the redshifts of large numbers of galaxies simultaneously. It had two sets of 400 fibres that were robotically positioned and two spectrographs.[59] The 2dF's opening ceremony was held on 20 November 1995 and the first useful spectra with it were taken in mid-1996. The main initial project with the new instrument was to map out the nearby universe with the 2dF Galaxy Redshift Survey (2dFGRS) that obtained 230,000 redshifts.[60] The survey had a major international impact with forty-two refereed papers by the team that built it; up to 2010 they had 7797 citations.[61] According to the SAO/NASA Astrophysics Data System, currently (2023) 364 papers have mentioned 2dFRGS in their abstracts.

2006–2015: member numbers increase, especially in the west

In this period there was a sharp expansion of astronomy at a number of universities. These included Monash and Macquarie universities, as well as the universities of Melbourne and New South Wales. However, the two main success stories, as shown on Fig. 7, were at the Swinburne University of Technology and

[53]CSIRO (*n.d.*).
[54]National Committee for Astronomy of the Australian Academy of Science (2001) pp. 16–17.
[55]Nishijima (2002).
[56]National Committee for Astronomy of the Australian Academy of Science (2001) p. 46.
[57]Duldig and others (2016).
[58]Wong and Melatos (2002).
[59]Cannon (2011) pp. 78–79.
[60]Lahav (2004).
[61]Colless (2011).

at two Western Australian universities, the University of Western Australia and Curtin University.

In 1992, Swinburne Technical College was granted university status and became Swinburne University of Technology.[62] Six years later, Matthew Bailes was headhunted to join the staff of the young university, where he founded the Centre for Astrophysics and Supercomputing.[63] Linking astrophysics with supercomputing was especially innovative and enabled the centre to '… start solving some of those really deep problems using that supercomputer'.[64] In addition to the supercomputer, the centre has a number of unique features, such as advanced visualisation facilities and guaranteed access to two of the largest optical telescopes in the world, the twin 10-m Keck telescopes on Mauna Kea, Hawaii.

With Australia bidding to host the Square Kilometre Array (SKA) at a radio-quiet site in Western Australia, two Western Australian universities, Curtin University and the University of Western Australia, set up the International Centre for Radio Astronomy Research (ICRAR). This joint venture, aided by the WA State Government, was launched on 1 September 2009, and has nodes at both universities. ICRAR's '… research focus is the scientific capabilities enabled by the SKA and its pathfinders and the technology necessary to realise these new capabilities.'[65] Three years after the formation of ICRAR, in May 2012, the decision was made that the SKA is to be shared between Australia and Southern Africa. Australia is to host SKA-Low, an array to observe at low radio frequencies.[66] ICRAR has been scientifically most successful with ICRAR affiliated authors publishing 2985 refereed papers that have had 124,917 citations, up to September 2024.[67]

There are three SKA precursor instruments, two of which are in Western Australia at *Inyarrimanha Ilgari Bundara*, the Murchison Radio-astronomy Observatory (MRO), the future home of SKA-Low; the third one is in Southern Africa. One of the two in Australia is the Murchison Widefield Array (MWA), built by an international consortium led by Curtin University. Operating at the low radio frequencies of 80–300 MHz, it consists of 128 aperture arrays, known as tiles, spread over a circle of 3-km diameter.[68] The opening ceremony for the MWA was held remotely at the ASA's 2013 Annual Science Meeting. The large field of view of the telescope makes it most suitable for wide field sky surveys. Science goals of the MWA include looking at neutral hydrogen from the epoch of reionisation, the period of the formation of the first stars and galaxies in the early Universe. A second goal is a survey of the full southern hemisphere sky below 10° declination.

The other SKA Precursor telescope at MRO is the Australian Square Kilometre Pathfinder (ASKAP), developed by the CSIRO. Like MWA, it also has a wide field of view that makes it suitable for fast surveys of the entire sky. However, it operates at a higher frequency of 700–1800 MHz.[69] It consists of thirty-six antennas, each with the unique feature of a phased array feed with multiple receivers enabling the large field of view. One of the surveys with the telescope is the Evolutionary Survey of the Universe (EMU) that aims to survey the entire southern sky at a frequency of 1.3 GHz.[70] It is expected to catalogue approximately 70 million galaxies, including star-forming galaxies and very distant active galactic nuclei.

Another new survey telescope, this time in the optical, is SkyMapper. Located at the ANU's Siding Spring Observatory, this is a wide-field, fully robotic survey telescope with a 1.35-m primary mirror. It has a detector with 268 million pixels that gives a field of view of 2.4° by 2.3°.[71] Since commissioning ended in March 2014, observing with the telescope has been mainly dedicated to two surveys. One is the SkyMapper Southern Survey, based on observations made during good atmospheric conditions. The first data release was in December 2017 and had approximately 285 million unique astrophysical objects in 20,200 square degrees of sky. Time when atmospheric conditions are poor is used for a survey of transient objects, such as supernovae.

2016–2023: restructuring and gravity waves

Until June 2010, the Anglo-Australian Observatory (AAO) was jointly operated by the Australian and United Kingdom governments.[72] For the next eight years its management was solely by the Australian Government, as the Australian Astronomical Observatory, after which its management was transferred to a consortium of Australian universities. This led to the split of the AAO into two entities: Australian Astronomical Optics, which became a department within the Faculty of Science and Engineering at Macquarie University, and telescope operations

[62] Swinburne University of Technology (2017).
[63] Wilmoth (2022).
[64] Williams (2023).
[65] Wheeler and Gottschalk (2011).
[66] Wheeler and others (2013).
[67] Astrophysics Data System, funded by NASA under Cooperative Agreement 80NSSC21M00561.
[68] Tingay and others (2013).
[69] Leahy and others (2019).
[70] Norris and others (2013).
[71] Wolf and others (2018).
[72] AAO Macquarie (2023).

at Siding Spring Observatory, managed by the ANU. The telescope itself stayed the Anglo-Australian Telescope, so that its acronym remained the same (AAT). These management changes meant that, as shown by the crashing numbers in Fig. 5, the Australian Astronomical Observatory no longer exists. Like many universities, Macquarie had an increase in ASA members since 2000, but the creation of Australian Astronomical Optics as a department again boosted the numbers, as shown in Fig. 7. The new department is a founding partner in the Astralis Instrumentation Consortium (Astralis), which includes the Australian National University and the University of Sydney. Astralis has significant expertise in building astronomical instrumentation utilising innovative technology, such as photonics to capture and filter light.

The restructuring of the AAO was a direct consequence of Australia entering a ten-year partnership with the European Southern Observatory (ESO) in July 2017.[73] This partnership allows Australian astronomers access to the ESO's telescopes in Chile, including the four 8-m telescopes making up the Very Large Telescope (VLT). The operational savings to the Australian Government of the change in structure of the AAO was expected to be $25.2 million, spread over two financial years. This largely offset the initial expenditure of $26.1 million, over four financial years, on the ESO partnership. Not only does the partnership allow Australian astronomers access to large telescopes, but it also provides opportunities for Australian expertise in advanced astronomical instrumentation, such as at Macquarie University's Australian Astronomical Optics, the Australian National University and the University of Sydney, to contribute to the instrumentation on those telescopes.

On 14 September 2015, the Advanced Laser Interferometer Gravitational-Wave Observatory (aLIGO) in the USA announced that it had detected gravitational waves from the collision of two black holes.[74] There were some Australian astronomers already involved in the exciting new field of gravitational astronomy, while others quickly joined. The Zadko telescope, a 1-m Cassegrain robotic telescope, is operated by the University of Western Australia with the aim of searching for transient events in the sky.[75] For the first aLIGO observing run, the Zadko telescope was one of sixty-three global partners that searched for possible electromagnetic counterparts to the sources of gravitational waves. Another telescope to search for optical counterparts of gravity wave events is the SkyMapper telescope at Siding Spring Observatory (discussed in the previous section). The software on this telescope was upgraded so that it can quickly respond to alerts about gravitational detections and start taking and analysing images in the appropriate area of the sky.[76]

A different way to search for gravitational waves, one that is independent of aLIGO and its sister facilities, is that of the Parkes Pulsar Timing Array.[77] This project has been taking precise measurements of pulsar arrival times from twenty-six ms pulsars since 2006. In a highly promising result, analysis of the latest data release from the project suggests possible 'fingerprints' of gravitational waves.[78]

The disparate groups in Australia involved in this new window on the Universe have been brought together in the Australian Research Council Centre of Excellence for Gravitational Wave Discovery, known as OzGrav.[79] Hosted by Swinburne University, the centre began operating on 6 April 2017. It is a partnership between Swinburne, the CSIRO and a number of Australian universities, including Monash, Adelaide and the Australian National universities, and the universities of Melbourne and Western Australia.

The Astronomical Society of Australia and the Australian astronomical community

In this paper we focused on changes in Australian astronomy through the impacts on the numbers and locations of ASA members. However, it is of interest to see how representative the ASA is among the Australian astronomical community. To get an idea of this, we used the demographic survey prepared for the mid-term review of the 2016–2025 decadal plan by the Australian Academy of Science's National Committee for Astronomy (NCA).[80] This survey provided the numbers of staff engaged in astronomical research at fifteen Australian universities and institutes in 2019/20. As shown in Table 1, we compared the numbers for each institution with ASA memberships at the same institutions using the ASA 2020 membership list. The mean of 73 ± 5% (standard error) shows that the ASA does represent the majority of Australian astronomers. Moreover, a strong correlation of 0.93 between the total number of astronomy researchers at each institution and ASA members, shows that changes in ASA demographics provide good indications of corresponding changes in the total numbers at relevant universities or institutions.

Table 2 shows the same comparison for postgraduate students at the listed institutions. Though the mean of 68 ± 6% is a little lower than for staff, it still shows that the majority of the student population are student members of the ASA. Again, with a correlation of 0.81 between total

[73] Beckmann and Hanna (2018).
[74] Castelvecchi and Witze (2016).
[75] Coward and others (2017).
[76] Chang and others (2021).
[77] Zic and others (2023).
[78] Chesters (2023).
[79] OzGrav (2017).
[80] National Committee for Astronomy (2020).

Table 1. Fraction of ASA members permanent or contract at different universities and institutes in 2020.

University or institute	Queensland	Western Sydney	Macquarie	ANU RSAA	Adelaide	Swinburne	New South Wales	Curtin Inst. R Astron	ICRAR WA	Monash	Sydney	CASS	Tasmania	Southern Queensland	Melbourne	Totals/ Average
Total astronomers	5	5	17	57	5	46	15	46	36	24	31	47	9	16	18	377
ASA members	6	5	21	34	5	36	16	24	31	18	17	36	5	10	11	275
Percent ASA members	100	100	100	60	100	78	100	52	86	75	55	77	56	63	61	73

Notes: (1) Total astronomer numbers at each institute from https://www.science.org.au/files/userfiles/about/documents/demographics-paper.pdf. Fractional numbers 0.5 or more rounded up to the nearest integer. (2) ASA members from the 2020 ASA members list. (3) As the demographics paper linked above does not include those from Canberra in the count for the University of New South Wales, neither do the listed ASA members.

Table 2. Fraction of ASA student members at different universities and institutes in 2020.

University or institute	Queensland	Western Sydney	Macquarie	ANU RSAA	Adelaide	Swinburne	New South Wales	Curtin Inst. R Astron	ICRAR WA	Monash	Sydney	CASS	Tasmania	Southern Queensland	Melbourne	Totals/ Average
Total students	7	8	21	47	15	51	8	24	28	26	34	0	12	26	29	336
ASA members	3	7	13	32	8	44	16	11	18	32	13	1	8	10	11	227
Percent ASA members	43	88	62	68	53	86	100	46	64	100	38	100	67	38	38	68

Notes: (1) Total PhD student numbers at each institute from https://www.science.org.au/files/userfiles/about/documents/demographics-paper.pdf. Part-time students at University of Southern Queensland are each included. (2) ASA student members from the 2020 ASA members list. (3) At a few places there are more ASA student members than the listed total. This is likely to be mainly due to students who have completed their degrees but not yet reported it to the ASA. As well, some students from schools other than physics or astronomy may not have been included in the demographics paper linked above.

numbers at each institution and the corresponding ASA numbers, demographic changes in ASA student members should provide good indications of changes in the total numbers.

Discussion

Astronomy has changed dramatically since the 1960s, in ways that would have been unimaginable to the astronomers of the time. Surveys of vast areas of the sky involving the international collaboration of large number of astronomers are at the forefront of research. An indication of the numbers can be seen from the author list of three recent papers, to which we have referred previously, each with more than thirty authors.[81] These can be contrasted with papers published in the first year of the ASA's *Proceedings*, that is, in 1967: sixty-one papers published, with thirty-nine single author, eighteen two author, one three author and one four author.

High performance computing (HPC) has become essential for astronomy. It is used for large theoretical simulations, as well as for the processing and analysis of the large streams of data from modern telescopes, such as SkyMapper and ASKAP.[82] The main HPC facilities available to astronomers are the supercomputers at the Pawsey centre and at the National Computational Infrastructure.[83] The supercomputer at the Swinburne Centre for Astrophysics and Supercomputing also assists astronomers.

The expansion of astronomy over the last fifty years or so would not have been possible without government support. This has been helped by the National Committee for Astronomy (NCA), set up by the Australian Academy of Science. Though the NCA is separate from and independent of the ASA, it is closely related, as for example, its current (2023) chair is Swinburne University's Virginia Kilborn, who was the president of the ASA in 2015 and 2016. Decadal plans prepared by the NCA and published by the academy allow astronomers to speak with one voice in setting out needs and priorities for the coming decade. This is important when informing stakeholders, especially Australian governments at both federal and state levels, as they provide the bulk of the funding for astronomical research. Funding sources originating from government include the Australian Research Council (ARC), the universities, CSIRO and Astronomy Australia Limited.[84]

Centres of excellence in astronomy, funded by the ARC, have been major facilitators of change in Australia. The two current centres are the previously mentioned OzGrav, and ASTRO 3D, the inaugural director of which was Lisa Kewley at the Australian National University.[85] With over 400 astronomers involved in the two centres, they provide collaborative opportunities for world-class research, as well as training for postdoctoral researchers and PhD students.[86] They are also conduits for the funding of astronomical research. In 2020, centres of excellence received approximately $9M out of approximately $23M annual funding allocated by the Australian Research Council to astronomy.[87] These centres build on the legacy of the ARC Centre of Excellence for All-sky Astrophysics, known as CAASTRO, that was funded from 2011 to 2018.[88]

Since its formation in 1966, the ASA has significantly assisted with the development of astronomy in the country. Its annual scientific meetings allow astronomers to hear about the latest research being carried out at institutions other than their own and, more importantly, facilitates networking with colleagues to build collaborations. The annual Harley Wood school educates young astronomers, while letting them form the connections that will be important for their future careers. The *Publications* of the society give astronomers the opportunity to publish in a leading astronomical journal.

There have been many changes in Australian astronomy since 1966. Though future developments are hard to predict, an indication can be deduced from the latest mid-term review of the current decadal plan.[89] Priorities listed include full membership of the European Southern Observatory, realisation of the full SKA and funding the design and development of an Australian gravitational wave pathfinder. However, these priorities may change in the 2026–35 decadal plan that is currently being developed.

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81 Norris and others (2013). Tingay and others (2013). Zic and others (2023).
82 National Committee for Astronomy (2020) p. 41.
83 National Committee for Astronomy (2020) p. 53.
84 National Committee for Astronomy (2020) pp. 23–25. Astronomy Australia Ltd. (2024).
85 ARC (2017).
86 National Committee for Astronomy (2020) p. 11.
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