ASTRONOMY IN AUSTRALIA—A BRIEF HISTORICAL SURVEY

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Received April 1999

Abstract

> An astronomical event, the transit of Venus at Tahiti in 1769, led to the discovery of Eastern Australia by Captain James Cook and its colonization by the English in 1788. Beginning that very first year, an observatory was erected, and ever since, Australia has played significant roles throughout the history of astronomy. Now the modern optical observatories at Mount Stromlo and Siding Spring have become important and friendly centers for international cooperation in research. In modern radio astronomy, Australia has been an outstanding pioneer.

1. Introduction

An unusual celestial event, a transit of the planet Venus over the face of the sun on June 3, 1769, as observed from Tahiti, serendipitously led to the British colonization of eastern Australia. Transits of Venus are rare; they have been observed only in 1631, 1639, 1761, 1769, 1874, and l882. The next will not occur until 2004 and 2012.

After a somewhat vague suggestion by Kepler (1571–1630) that transits of Venus could be used for the determination of the distance to the sun, Jermiah Horrox (1619–1641) successfully predicted the 1639 passage and observed the transit from a location near Liverpool on November 24, 1639 (Kitson 1907), estimating therefrom that the parallax of the sun must be less than 14" (Woolf 1959, p.12). For determining the parallax of the sun, Edmund Halley (1656–1742) in 1716 pointed out that precise observations of transits were needed for determining the solar distance, which at that time could not be determined with sufficient accuracy by any other means. Halley observed a transit of Mercury in November 1677. As the result was disappointing, he indicated that durations of transits of Venus observed from widely separated positions on the earth would be far superior. He estimated that the times of transit could be measured to an accuracy of two seconds, yielding the distance to the sun to one part in 500 (Berry 1899). He strongly advocated that efforts be made for such observatons at the transit of 1761, an event he himself would not live long enough to observe (Cruikshank 1983). Transits, when they occur, cannot be seen from everywhere on the globe (*e.g.*, not when the transit is after dark, as happened in Europe at the time of the transit of Venus in 1761).

Nevil Maskelyne (1732–1811), Astronomer Royal and in 1766 the founder of the *British Nautical Almanac*, in conjunction with members of the Royal Society Council, sent a memorandum to King George III strongly urging him to subsidize expeditions to far-away sites, especially to the South Seas, to observe the transit of Venus in 1769. They stated in part (Kitson 1907, p. 85):

> That the British Nation have been justly celebrated in the learned world, for their knowledge of Astronomy, in which they are inferior to no Nation upon Earth, Ancient or Modern; and it would cast dishonour upon them should they neglect to have correct observations made of this important phenomenon.

Moreover,

> That by neglecting to take the necessary precautions in due time, the passage of the Planet in the year 1761 was not observed in some places from whence the greatest advantages might have redounded to the improvement of Astronomy.

The response was favorable. Maskelyne originally recommended Alexander Dalrymple (1737–1808) to go to the South Seas, as he had already made voyages ostensibly discovering a new southern continent (Dalrymple 1767). Dalrymple, although anxious to get the appointment, insisted that he be in complete command of the vessel to be commissioned. This the Royal Navy refused to allow. From past experience with mutiny when a civilian (Edmund Halley in 1698) had been put in charge, now none but an officer of the Royal Navy (R.N.) could be commissioned to control a vessel of the Navy (Forman and Syme 1971).

King George III then commissioned Lt. (later Captain) James Cook, R.N. (1728–1779) (Figure1) to sail to Tahiti, the largest of the Polynesian Islands, named Society Islands by Cook. The first European to have discovered the Island was Pedro DeQuiros in 1607, but that was apparently forgotten until the island was rediscovered by Englishman Samuel Wallis in 1767 (von Hügel 1888). Wallis returned to England in May 1768 (Price 1958), just in time as the British Royal Society was considering where Cook should best go to observe the transit. Cook was chosen for heading the expedition to Tahiti not only because of his successful surveying of the waterfronts of Newfoundland (1763–1767) but also because of his successful observations while there, of the total eclipse of the sun on August 5, 1767, from which he deduced the longitude of his observing site (Kitson 1907, p. 76; Campbell 1936, p. 43).

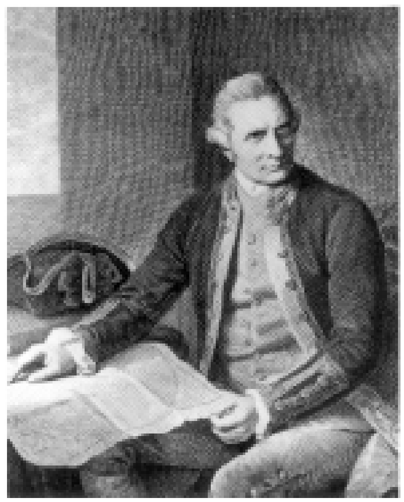

Figure 1. Captain James Cook, R. N., F. R. S. (1728–1779).

2. The Transit of Venus and a Search for a Suspected Southern Continent

Once the bark *Endeavour* was properly outfitted for its arduous journey, Cook and a company of 94 set sail from Plymouth on 26 August 1768, sailing southwestward to Rio de Janeiro, rounding Cape Horn, and then across the Pacific to Tahiti where they anchored 13 April 1769. Cook named the site they chose for observing the transit Port Venus (the place where there is now a monument to Cook).

The observations of the transit were carried out by Cook, astronomer Charles Green of Greenwich Observatory, and Danish naturalist (and former student of Linnaeus) Dr. Daniel Solander. Their observations did not yield the accuracy hoped-for, largely because it was not yet appreciated that Venus has an atmosphere which blurs the contact points at the solar limb, called the black drop effect, making the important timing of the contacts uncertain. Nevertheless, their results were an improvement over previous determinations. W. H. Robertson (1970) summarized the accomplishments of the 1761 and 1769 missions for the determination of the solar distance as “the first major international effort in observational astronomy,” in which Cook and Green played a major role. The combined results of all the observers of this transit yielded a solar parallax of 8" or 9", later re-reduced by Encke in 1835 yielding 8.571" (Berry 1899, p.366) corresponding to a distance of about 95 million miles, as compared with the current parallax of 8.794", corresponding to a distance of about 93 million.

The next transits, of 1874 and 1882, were widely observed in Australia, as elsewhere. For example, Government Astronomer H. C. Russell (1892) gives detailed accounts of numerous observers in New South Wales, especially discussing the black drop effect. This was the first transit of Venus to which photography could be applied, and plates were taken with the Sydney 11.4-inch refractor. The black drop seen visually was not revealed on the photographs.

After the transit of 1769, Cook’s instructions were to travel Westward, trying to confirm Dalrymple’s reported discovery of a southern continent. Dalrymple had remarked, “The space unknown from the Tropics to 50° South Latitude must be nearly all land” (Price 1958). The western shore of New Zealand was assumed to be a boundary of that continent. It had been discovered by the Dutch explorer A. J. Tasman (1603–1659) in 1642, but he never set foot on the land, partly because of the apparent hostility of the canabalistic native Maoris, on shore and in boats. Tasman had discovered only the Western shore of North Island. On October 7, 1769, Cook approached from the East and navigated the entire coast of both islands, the whole spanning Latitudes 34° 35' S to 47° 17' S and East Longitudes 166° 26' to 178° 36'. He noted that what had been described as a bay was in fact a channel, now named Cook Strait, separating North from South Island.

From shipboard, on August 29, 1769, before New Zealand was sighted, a comet was observed, Comet Messier 1769 (Mucke 1972). The Polynesian who had joined the ship in Tahiti was alarmed, saying the comet forebode evil for his people.

3. Discovery of Eastern Australia

Having accomplished his two assigned missions, observing the transit and ascertaining whether or not there was a large southern continent of which New Zealand was the Eastern boundary, Cook and his officers were privileged to return to England by whatever route they desired. As weather conditions along the direct southern routes around either Cape Horn or Cape of Good Hope promised to be hazardous at that time of the year, Cook decided instead to head northward toward the East Indies. He was aware that New Holland, as Australia was then known, had been explored along its Northern, Western, and Southern boundaries by the Dutch, Portugese, or Spanish, but the Eastern coast was completely unknown to Europeans.

Cook hoped especially to sight Van Dieman’s Land (now called Tasmania after its discovery by Tasman in 1642). Land was first sighted at Point Hicks, named for the young sailor who was the first to spot it on 19 April 1770, at Latitude 38° S. Cook was unable to see any signs of Tasmania from there, the northern coast of Tasmania being about 41° S. Stormy seas prevented him from sailing farther south. Therefore he inferred that Tasmania was probably an island, not part of the continent, for otherwise he should have seen land to the south of where he was. Sailing north along the coast *Endeavour* first anchored at what is now Botany Bay, near but not at Sydney Harbor. Exploring farther North he made numerous stops to determine latitudes and longitudes from lunar observations.

Good chronometers suitable for longitude determination were not perfected until 1785, although John Harrison (1693–1776) had succeeded in 1762 in constructing one accurate to within three seconds in a six-week’s voyage, yielding the longitude to within 34 miles. However, the chronometer was too delicate, complicated, and too

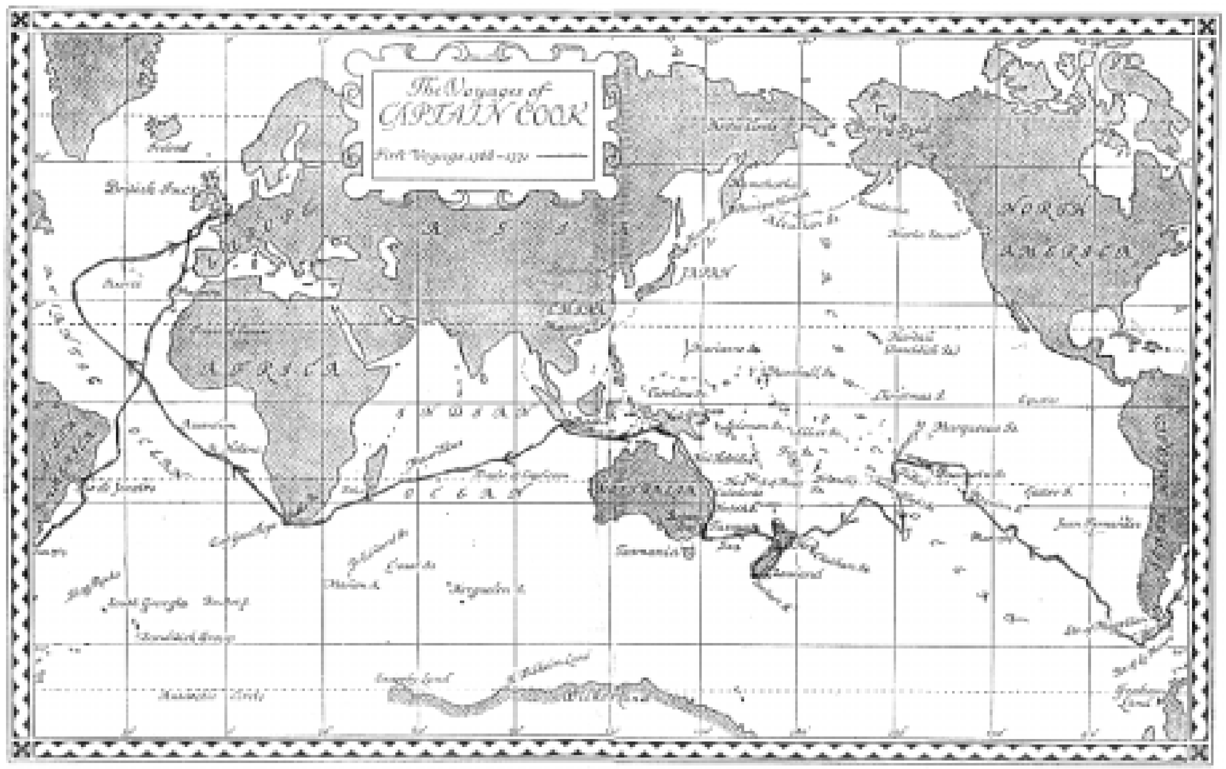

Figure 2. The path of Cook's voyage 1768–1771. From Gordon Campbell, *Captain James Cook, 1936*, inside front cover.

costly for common use at sea (Furer and Moody 1993). Cook, however, obtained one of Harrison's design made by Larcum Kendall for his next voyage in 1772, when he systematically compared the chronometer results with then time-honored lunar observations, concluding that Kendall's clock yielded the more accurate results (Kitson 1907, p. 273).

Tragedy struck on June 10, 1770, when *Endeavour* crashed on a coral reef at 11 o'clock at night, near a point Cook appropriately named Cape Tribulation (Forsyth 1970). With all on board helping with pumping the excessive intake of water, it is nothing short of a miracle that the ship was finally afloat by July 4, after jettisoning some 40 to 50 tons of ballast and equipment, though still in worse condition than the officers realized. Sailing through Torres Strait (latitude about 10˚ S), thereby disproving a contention that New Guinea was a part of Australia, the ship finally arrived at Batavia, Java, on October 10, where the Dutch helped put the vessel in better shape. She was not adequately overhauled until December 26, when she proceeded toward South Africa's Cape, ultimately reaching England on July 13, 1771, just one month short of three years from her departure. (See Figure 2 for the round trip path.)

4. Colonization and First Observatories

Cook's explorations ultimately led to the British colonization of Australia. While earlier explorers of the northern and western shores had not found the land suitable for colonization, Cook clearly considered the eastern lands promising. Before the American Revolution, Britain had sent convicts to American Georgia. After the war, that practice could not continue. Hence, in 1788 Captain Arthur Phillip was dispatched with 700 convicts to establish a colony at Botany Bay. The astronomer, 2nd Lieut. William Dawes, was sent along in order to set up an observing station to hunt for a comet whose return in 1889 had been predicted by Halley, who assumed that a comet discovered by Apian in 1532 and another by Hevelius in 1661 were the same. The comet prediction was evidently erroneous. But Dawes sketched the south shore of Sydney Harbor in 1788 and marked the spot where he erected his observatory, the first in Australia, at 31˚ 52' 30" S, 151˚ 15' 30" W, close to the later position of the Sydney Observatory (Wood 1951, 1958, and 1973a).

In 1821 Sir Thomas Makdougall Brisbane (1773–1860), a British soldier and astronomer, was appointed Governor of New South Wales, Australia. At Paramatta, about 14 miles from Sydney, he built an observatory equipped with a transit instrument, a 46-inch achromatic reflecting telescope, and sundry other equipment. There, between 1822 and 1826 (when he returned to England), he and two assistants, K. L. C. Rümker (1788–1862, from 1831 Director of the Hamburg Observatory) and J. Dunlop (1793–1848) carried out extensive observations of southern stars—stars not previously observed scientifically since de Lacaille's trip to the Cape of Good Hope in the early 1750s. The Paramatta *Catalogue* of 7385 mainly southern stars was compiled and published by W. Richardson of the Greenwich Observatory in 1835. De Lacaille's catalogue, published in 1763, contained only 1942 stars.

The Paramatta astronomers were also successfully on the lookout for the return of a comet discovered by J. L. Pons in 1818, for which J. F. Encke had computed an orbit indicating the comet would reappear in 1822 (Hind 1852). This was only the second comet for which an orbit had been computed, and as in the case of Comet Halley, was named after the person who successfully predicted its return (Encke) rather than after the original discoverer. Encke's comet has the shortest period known for any comet, 3.3 years. It had been observed as far back as 1786. Rümker and Dunlop in 1824 discovered two new comets and in 1834 Dunlop discovered another.

The current city of Brisbane in Queensland was founded by John Oxley in 1824 and named in honor of Sir Thomas Brisbane. An observatory was built in 1829 by the convicts brought over from England. In his first article entitled *Astronomy in Australia*, Wood (1951) commented that one of the basic needs for astronomy in Australia was "a vital school of astronomy associated, if possible, with an observatory." By 1958 there was a university in each of the capitals of the six states of Australia (Sydney, Melbourne, Brisbane, Adelaide, Perth, and Hobart) with Sydney and Melbourne sharing highest prestige (Davies 1958). But in his second historical article, Wood (1973a, p. 22) noted that by 1950 there had been no professor or lecturer in astronomy or astrophysics in any Australian university. The earliest (*idem*, p. 19) was in 1958 at the Physics Department of the University of Queensland where Professor D. Mugglestone began research in astrophysics, and with his students engaged in spectral analyses of the solar atmosphere. (The University of Queensland had been founded in 1909.) By 1973 nearly every university in Australia was actively pursuing astronomy or astrophysics.

5. An Important Early Amateur Astronomer

Figure 3. John Tebbutt (1834–1916).

Amateur astronomers worldwide have made notable contributions to observational astronomy. In Australia, John Tebbutt (1834–1916) (Figure 3) was an outstanding early example. In 1854 he built his own observatory (Figure 4) at Windsor, some 30 miles Northeast of Sydney (Tebbutt 1887). Here, with at first only a sextant, he discovered a comet in 1861. The Earth was found to have travelled through the tail of this comet. He made extensive observations of Comet 1862 III, using nearby stars as reference stars for detecting changes in its position. Much later, Tebbutt (1878) discovered that one of the reference stars, 4th or 5th magnitude on the nights of October 4, 5, 6, and 9, 1862, did not appear in any star catalogues available to him. He searched the field on November 13, 14, and 17, 1877, and found a star 10–11 magnitude at R.A. $17^{h}\,35^{m}\,31^{s}$, Dec. $-45^{\circ}\,27'.1$ (1950), the position of the former bright star (Gore 1899; Ashbrook 1972). This object was first named V728 Sco in the second edition of the *General Catalogue of Variable Stars* (Kukarkin *et al.* 1958). In the fourth edition (Kholopov *et al.* 1987) it has been appropriately listed as a questioned nova. However, it seemed never to have been examined on any existing photographic plates to ascertain if by any chance it is a recurrent nova. Its position is shown in Norton's 2000.0 Star Atlas (Ridpath 1989), and in the *AAVSO Variable Star Atlas* (Scovil 1990). It is not bright on any of the 300 available Harvard plates of the AM series (1.5-inch lens, scale 600" per millimeter, limiting magnitude 12pg) centered at -45° taken between August 5, 1899, and September 12, 1953 (Hoffleit 1996).

Tebbutt also made many observations of solar system objects, double stars, and variables, and computed cometary orbits. An obituary (Anon. 1917) states, "In a nascent colony in which the conditions of life were adverse to scientific study, and where the stimulus of sympathetic companionship was utterly wanting, he worthily upheld the claims of intellectual study, and struggled manfully in the pursuit of research." When William Scott, the first Director of the Sydney Observatory, resigned in 1862 the position was offered Tebbutt. By that time, however, Tebbutt had acquired a 4.5-inch Cooke and an 8-inch Grubb refractor, and felt he could accomplish more by staying with his own better-equipped observatory. In all, he published at least 387 papers in learned journals (Tebbutt 1908, and Evans 1988, p. 123, indicate 371 papers through 1907, after which, through 1915, he published sixteen more). His last published note (Tebbutt 1915) gave position angles and separations of the double stars α Centauri and γ Coronae Australis. α Centauri is so bright he measured it in full sunlight! Tebbutt clearly exemplified the original definition of amateur: one who loves and pursues the work he has chosen, regardless of compensation. For his era, this amateur did professional quality work. A crater on the Moon has been named *Tebbutt* in his honor (Contopoulos 1974).

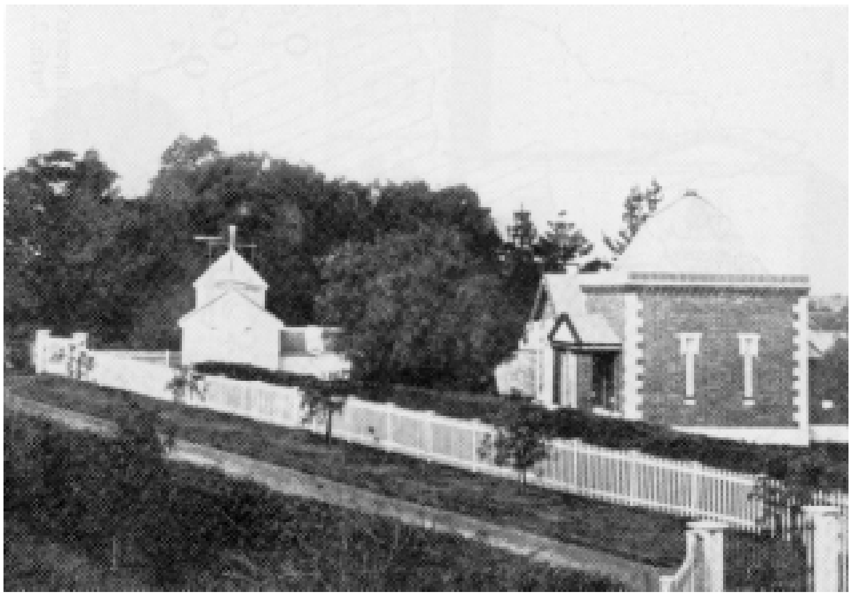

Figure 4. John Tebbutt's Observatory.

6. Numerous Optical Observatories

David Evans (1988) lists 19 optical observatories established at one time or another in Australia. About half of these were erected temporarily for observations of the transits of Venus or for the utilitarian purposes of the determination of latitudes and longitudes, time services, or solar observations for correlations with meteorological data. Most of the longer-lasting observatories (Table 1; Figure 5) carried out important observations for the determination of precise positions and apparent motions of the southern stars, contributing positions for well over 1.3 million stars. Such data are essential for the determination of the size, shape, and rotation of our galaxy, the Milky Way, a spiral system much like the famous Andromeda Nebula. As we are inside our galaxy we "cannot see the forest for trees" and must deduce its properties from various types of observations. For the observations of southern stars both Australian observatories (especially Sydney) and the observatories in South Africa have played the major roles. Other projects carried out by one or more of the Australian observatories included asteroids, comets, meteors, variable stars, clusters, the Milky Way, and galaxies (Evans 1988; Wood 1968, 1973a, b).

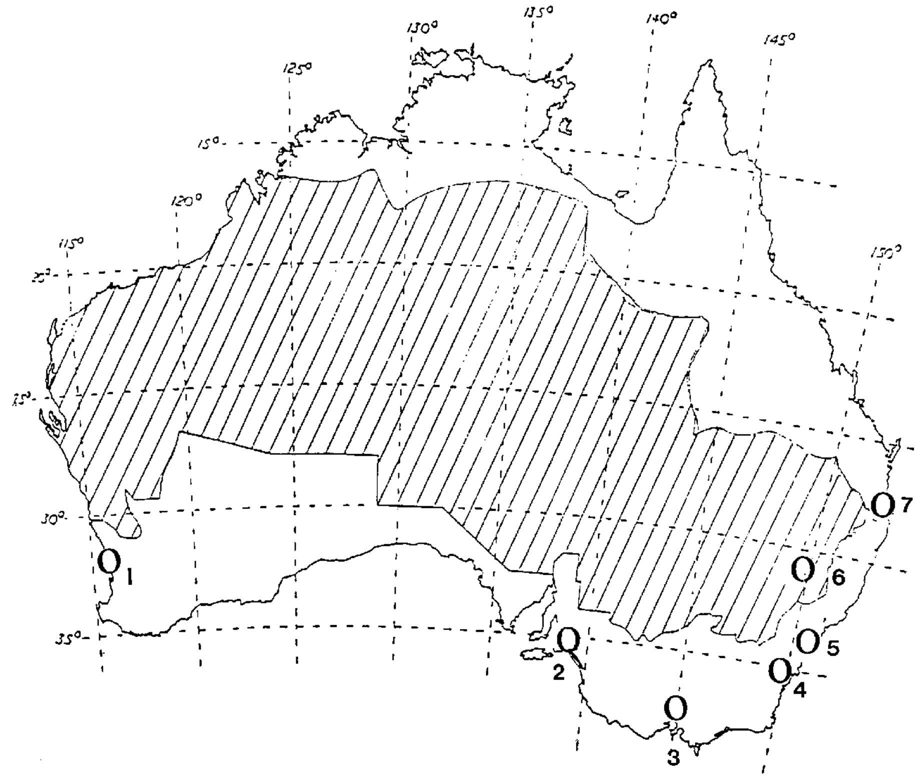

Figure 5. Locations of major Australian optical observatories plotted on map by H. Wood (1974). Shaded area is where the number of clear days is at least three times the number of cloudy. Only Siding Spring lies within this favorable area. 1. Perth; 2. Adelaide; 3. Melbourne; 4. Mount Stromlo; 5. Sydney; 6. Siding Spring; 7. Brisbane.

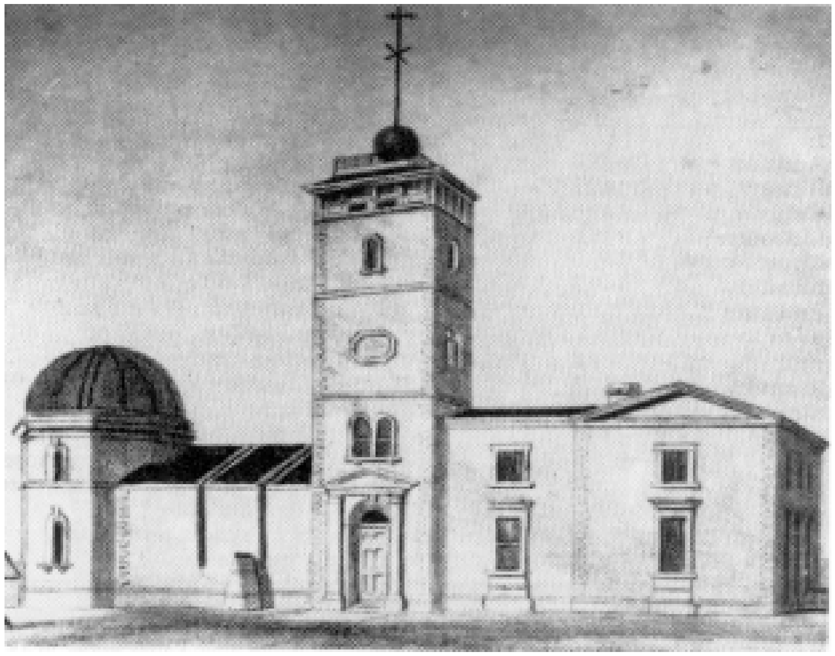

Figure 6. Original Sydney Observatory, 1859.

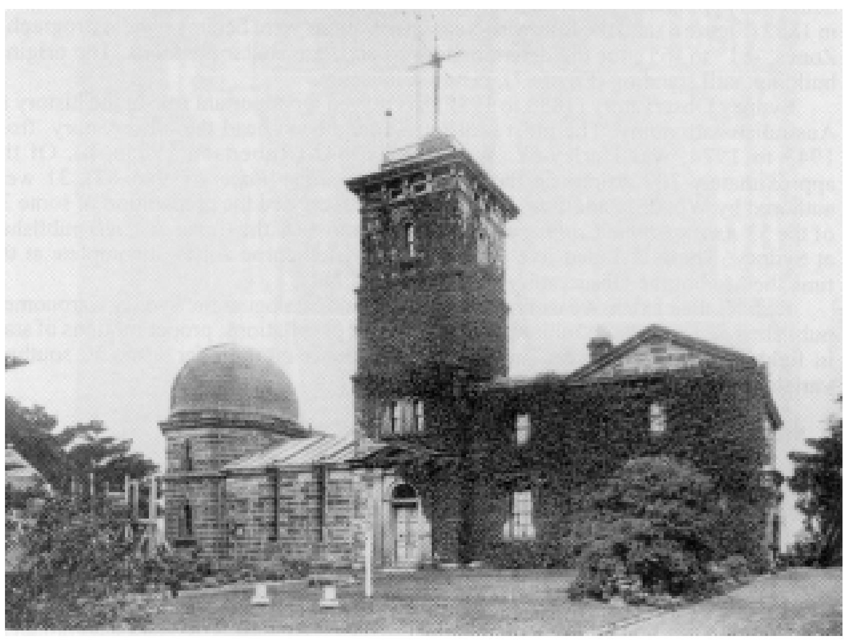

Figure 7. Recent view of Sydney Observatory.

Table 1. Important Australian Optical Observatories.

Name/Location	E. Long. °	S. Lat. °	Years	Principal Research
Adelaide	138.6	34.9	1874–1954	Jupiter; variation of latitude
Bickley*	116.1	32.0	1966–	Comets, asteroids
Culgoora	149.6	30.3	1967–	Solar (both optical and radio)
Melbourne	145.0	37.8	1861–1944	Astrometry
Mount Stromlo	149.0	35.3	1926–	Many, including MACHO
Narrabri	149.8	30.2	1963–	Mostly radio
Paramatta	151.0	33.8	1821–1847	Astrometry, The Brisbane *Catalogue*, comets
Perth	115.8	31.9	1896–1964	Astrometry
Riverview	151.2	33.8	1931–1959	Variable stars
Siding Spring	149.1	31.3	1964–	Many
Sydney	151.2	33.9	1856–1982	Astrographic Catalogues; minor planets, lunar occultations, proper motions of variable stars and of stars in cluster fields
Windsor (Tebbutt)	150.8	33.6	1854–1904	Solar system, double stars, variable stars

**Successor to Perth*

Sir William Denison became the Governor General of New South Wales in 1855 and it was due to his instigation that the Sydney Observatory was founded. William Scott was appointed the first Director, starting in 1856. The Observatory was erected in 1857 (Figure 6) and the following year observations were begun on the Astrographic Zones, -51° to -65°, for the determination of accurate stellar positions. The original building, still standing (Figure 7), is now a museum.

Sydney Observatory (1856 to 1982) has played an important role in the history of Australian astronomy. The most prolific astronomer to head that observatory, from 1943 to 1974, was Harley W. Wood (1911–84) (Robertson 1985a, b). Of the approximately 100 articles in the *Sydney Observatory Papers* (1946–83), 31 were authored by Wood. In addition, he authored or supervised the preparation of some 33 of the 53 *Astrographic Catalogues* (otherwise known as the *Carte du Ciel*) published at Sydney. These included five volumes of the Melbourne zones, incomplete at the time the Melbourne Observatory was closed in 1944.

Besides their extensive work on the astrographic catalogues the Sydney astronomers published extensively on minor planets and lunar occultations, proper motions of stars in fields of galactic clusters, and determined proper motions for some 30 southern variable stars (Wood 1982).

7. Mount Stromlo and Siding Spring

The Mount Stromlo Observatory outside Canberra (Figure 8), is the first really modern observatory in Australia (Lojkine 1957). It started out as The Commonwealth Solar Observatory in 1924, but when R. v. d. R. Woolley became the Director in 1939, the name was changed to Commonwealth Observatory and the range of interests expanded to cover the entire universe. In 1957, after Woolley left to assume the position of Astronomer Royal in England, and B. J. Bok left Harvard to become the new Director, the jurisdiction of the observatory was transferred to the Australian National University in Canberra, and the name finally changed to Mount Stromlo Observatory.

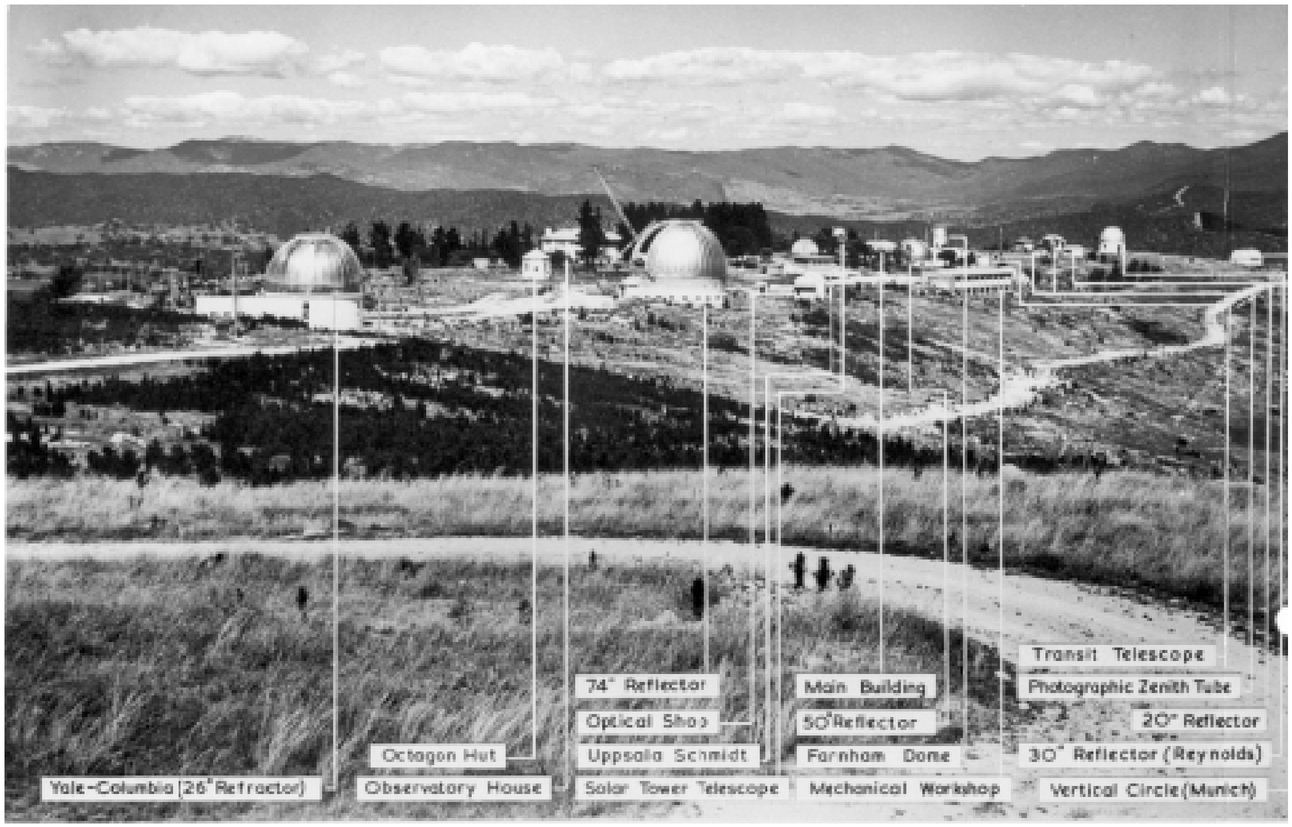

Figure 8. Mount Stromlo Observatory.

The oldest telescope on Mount Stromlo, the 9-inch Oddie telescope (named for its donor) had been erected in 1911 for site testing for a new observatory. World War I intervened in the establishment of the Mount Stromlo Observatory at the site of the Oddie telescope. The major equipment now consists of the 50-inch refurbished Melbourne telescope and a 74-inch reflector. The Yale 26-inch refractor was originally designed by Frank Schlesinger of Yale for determining the parallaxes of southern stars from Johannesburg, South Africa. When, for financial reasons, Yale could no longer operate the telescope full time, the telescope was shared with Columbia University, hence thereafter called the Yale-Columbia Observatory. As observing conditions in Johannesburg deteriorated the telescope was moved to Mount Stromlo in 1952, and donated to Mount Stromlo in 1963 when the Yale-Columbia operations terminated. Eventually, University of Virginia astronomers started using the telescope for the purposes for which it had been designed—parallax determinations. Also erected on the Mount Stromlo site is another 26-inch telescope, belonging to the University of Uppsala, Sweden. Mount Stromlo has become an international community: visiting astronomers from many nations are hosted there, making good use of a vast amount of modern equipment.

As Mount Stromlo is close to the Canberra metropolis, observing conditions progressively deteriorated. Extensive site-testing led to the selection of Siding Spring Mountain as the most suitable. The earliest telescopes erected there were 63-inch and 24-inch reflectors. Then in 1967 the governments of Australia and the United Kingdom jointly planned the construction of a 150-inch Anglo-Australian Telescope to be erected at Siding Spring. The telescope was ready and put into full-time operation in June, 1975, with approximately equal time allocated to British and Australian astromomers. In the first year of operation, observing times for 92 projects were approved.

Meanwhile the British had also erected at Siding Spring a 48-inch Schmidt-type telescope which was dedicated at the August 1973 meeting of the International Astronomical Union (Irwin 1973). In 1988 the jurisdiction of the telescope was turned over to the Anglo-Australian Observatory. In its 1992–93 annual report 112 proposals for observing time at the 150-inch, ranging from 1 to 6 nights; and 14 proposals for the Schmidt from 1 to 17 nights each had been approved. Telescope time was not allocated only to UK and Australian institutions; thirteen other countries were included in these proposals. The 1992–93 report alone listed 142 published articles resulting from these observations and the 1994 report indicated 166 research publications. The topics indicated widely diverse interests, covering almost the entire gamut of possibilities, from planetary atmospheres through the evolution of galaxies. Starting in 1978–79 with a few collaborators from the United States, by 1994 astronomers from 33 countries had participated in the use of the Anglo-Australian telescopes (Table 2).

Table 2. The Countries Whose Astronomers Used the Telescopes of the Anglo-Australian Observatory.

Australia	Greece	Poland
Austria	Hungary	Portugal
Belgium	India	Puerto Rico
Brazil	Ireland	South Africa
Canada	Israel	Spain
Chile	Italy	Sweden
China	Japan	Switzerland
Denmark	Korea	Taiwan
France	Mexico	Union of Soviet Socialist Republics
Finland	Netherlands	United Kingdom
Germany	New Zealand	United States

With the development of larger and more sophisticated telescopes and accessories, especially after World War II, few observatories could compete for funding to acquire the rapidly-developing newer instruments. Moreover, city lights and air pollution contributed to the decline of usefulness of many of the existing locations. Hence, most of Australia's optical observatories have progressively ceased to exist, their institutions cooperatively using the larger modern installations. In America, astronomers likewise largely share the facilities at Kitt Peak in Arizona and Cerro Tololo in Chile. In Australia, Mount Stromlo and Siding Spring Observatories are now jointly the most active and are (as already demonstrated) hosts to observers worldwide. Siding Spring has the enviable reputation of having the best available observing conditions year round, the number of clear days averaging about three times the number of cloudy (Wood 1974).

8. Happy Hunting Grounds for MACHOs

As modern telescopes reach apparently fainter objects, including both intrinsically fainter stars and intrinsically bright objects at fantastically greater distances, newer types of objects are occasionally discovered (Mateo 1994). Thus, after a search starting in 1990, observers at Mount Stromlo in 1994 reported four MACHOs among over 8 million stars in the Large Magellanic Cloud, each monitored an average of 300 nights (Cook 1994). MACHOs is an acronym for Massive Compact Halo Objects. What are observed are stars that suddenly appear brighter than usual, remaining bright typically for a few weeks or months, with uniquely characteristic light curves (Figure 9) having amplitudes of 0.5 to 2.5V. The interpretation of these phenomena is that a comparatively small, dense, invisible dark object acts somewhat like a lens, appearing to magnify the brightness of the more distant star it is transiting. The duration and amplitude of the brightening depend on the mass of the dark object and the distance between the star and the transiting object. These gravitational lenses are presumably in our own Milky Way galaxy and searches are under way to find MACHOs transiting over stars in our own galaxy. Already 45 have been suspected in the direction of the galactic bulge among over 20 million stars, each monitored some 700 times in two colors by a consortium of Lawrence Livermore (California) and Mount Stromlo astronomers (Aplin 1994), and the searches are continuing (Green 1995a–d). As a by-product in the course of these MACHO surveys, the light curves of 3000 galactic Cepheids and 7900 variables in the Large Magellanic Cloud have been determined (Aplin 1994).

9. Supernovae

Supernovae are the most spectacular of the exploding catagories of variable stars. They occur only infrequently in any one galaxy. At maximum brightness their intrinsic luminosity is comparable to the integrated luminosity of the entire galaxy. In 1987 Australian observers at Mount Stromlo discovered one in the Large Magellanic Cloud, magnitude 3.00V at maximum, now the most extensively studied of all the supernovae. Depending on the shapes of their light curves, supernovae have been divided into several different types. Nearly all the objects now classified Type Ia have been found to reach closely the same intrinsic brightness at maximum light. Hence, if their light curves are well observed so that the apparent magnitude at maximum is certain, they can be used to determine the distance of the parent galaxy. The distances and recessional velocities of the galaxies are important data for analyzing the size and evolution of the universe. All told, well over 700 supernovae of all types have been discovered since 1855. During May 1994 to May 1995, a total of 34 were discovered, 13 by astronomers in Australia. However, only a few have been suitable for distance determinations.

An amateur astronomer, the Rev. Robert Evans of Coonabarabran, N.S.W., Australia, merits special reecognition. Between 1980 and 1988, with telescopes reaching estimated magnitude limits of 14.5 and 15.4, Evans discovered 24 supernovae by

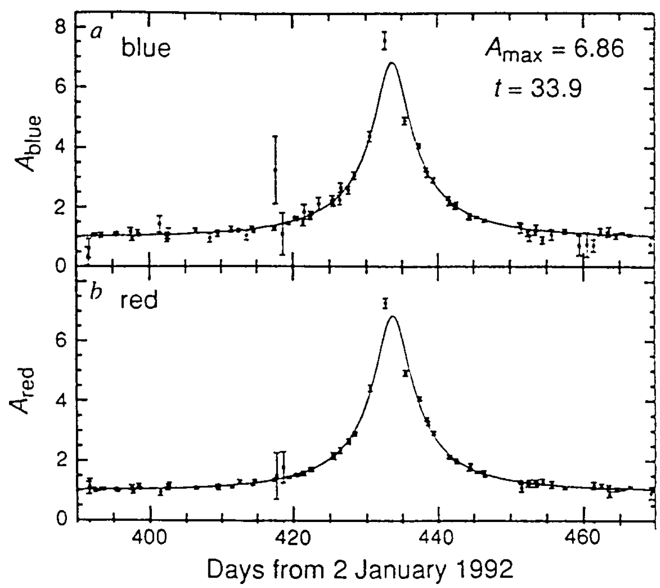

Figure 9. A typical light curve for a MACHO, one in the Large Magellanic Cloud (from Mt. Stromlo and Siding Spring *Annual Report* for 1993). The durations of maximum among those discovered range from days to months, the amplitudes from 0.5 to 2.5 magnitudes. (Here the amplitudes are given in instrumental units).

visually monitoring some 855 galaxies in the Shapley-Ames (1932) catalogue of galaxies brighter than photographic magnitude 13 (Tammann 1994; Evans 1992, 1995). Thus far, only two professional astronomers have exceeded Evans' record, both having had access to larger telescopes reaching fainter magnitudes than Evans'. In Australia R. H. McNaught of the Anglo-Australian Observatory discovered 25 between 1991 and May 1995, and C. Pollas of Côte d'Azur, France, found 51 between 1981 and 1995 (Pollas 1994; and more recent *IAU Circulars*). Evans, Chairman of the Supernova Search Committee of the American Association of Variable Star Observers, is the author of its *AAVSO Supernova Search Manual* (1993).

10. Rockets and Balloons for UV and X-ray Astronomy

Celestial objects radiate not only at visible wavelengths (from about 4000 to 6500 Angstroms). The electromagnetic spectrum covers a far greater range, from gamma rays at about 0.1 Angstrom to long wave radio at one meter. (An Angstrom is 10^{-8}cm.) Far ultraviolet and X-rays, wavelengths shorter than about 2000 Angstroms, do not penetrate the earth's atmosphere. Before the era of space flight was well under way, astronomers made attempts to record these wavelengths by launching rockets and high-altitude balloons. In Australia, a Skylark rocket launched from Woomera in South Australia on September 17, 1959, recorded the temperature of the sun in ultraviolet light at 8–10 Angstroms, finding it about 1.8 million degrees absolute Celsius—the temperature of the corona—in contrast to only about 5000° C for the photospheric temperature measured from ground-based instruments. Another Skylark launched

May 1, 1961, is reputed to have been the first to record ultraviolet radiation in the southern sky, at 1700 Angstroms (Boyd 1962). Starting in 1960, high-altitude balloons were being launched from Mildura, Victoria. In conjunction with the Universities of Adelaide and Tasmania, several flights carried equipment for X-ray astronomy (Wood 1973a, p. 21). These flights may have followed shortly after the Giacconi *et al.* (1962) first discovery of X-rays originating beyond the solar system during an Aerobee rocket flight launched from White Sands, New Mexico, in 1962 (Tucker and Giacconi 1985). While there is little record of early Australian successes, these early efforts merit recording.

11. Radio Observations

Although Karl G. Jansky in 1933 discovered radio waves emanating from the Milky Way (Jansky 1933), relatively little progress in radio astronomy was made until after World War II. While few of the original optical observatories in Australia have remained active, numerous radio observatories (Table 3) have sprung up since World War II (Wood 1973b). All except Hobart, on the island of Tasmania, are within an area about 140 by 260 miles. The index of Sullivan's treatise, *The Early Years of Radio Astronomy* (1984), cites 24 radio observatories worldwide, of which 12 are in Australia. In addition, at Adelaide and at Newcastle, about a hundred miles north of Sydney, radar observations of southern meteor streams were being carried out (Evans 1988, p.265). About 1948, Kerr (1984) made radar observations of the Moon, from a station in Hornsby (about 15 miles NNW of Sydney). The round trip transmission time of a radar pulse was just 2.5 seconds, indicating a distance of about 375,000 km., consistent with its orbital distance. The radar observations also contributed to investigations of the earth's ionosphere.

Radio astronomy was the direct outcome of radar research during World War II. A vast amount of electronic equipment had been accumulated in Australia and was being discarded as the country turned to activities in the interests of peace. A group of electronic engineers and industrialists rescued as much as they could of the materials that were destined for destruction and an organization called CSIR (Council for Scientific and Industrial Research), later changed to CSIRO (Commonwealth Scientific and Industrial Research Organization), was formed. Early developments in radio astronomy in Australia met with some indifference, even opposition. The distinguished Director of the Commonwealth Observatory at Mount Stromlo from 1939 to 1955, Sir Richard Woolley, had given a lecture on "The Future of Astronomy in Australia" in which he did not even mention radio astronomy. When asked where he believed that radio astronomy would be in ten years he replied "It will be forgotten" (Bowen 1984, p. 93). Fortunately, that statement may have become a challenge rather than a deterrent. 120 articles on radio astronomy were published by CSIRO personnel between 1946 and 1950.

Much of the early work in radio astronomy in Australia was devoted to solar research, but soon, projects concerning interstellar hydrogen, planetary atmospheres, the structure of the Milky Way, the rotation of the Magellanic Clouds, supernova remnants, pulsars, and more were undertaken. Perhaps the most exciting discovery in radio astronomy came in 1951 when H. I. Ewen and E. M. Purcell at Harvard detected the 21-cm line of neutral hydrogen in interstellar matter in the Milky Way. During wartime, H. C. van de Hulst of the Leiden Observatory had predicted that neutral hydrogen should be detected as the 21-centimeter line in the radio spectrum. Ewen and Purcell were hesitant to publish their results without independent confirmation. It so happened that van de Hulst and Australian Frank Kerr were radio astronomers visiting at Harvard at the time. They were encouraged to contact their countries to seek the desired confirmation, which was quickly secured. Kerr (p. 138) later commented, "This whole episode was a fine example of international cooperation, which has always been the hallmark of most of the relationships in radio astronomy."

Table 3. Australian Radio Observatories.

Name	E. Long °	S. Lat °	Year	Partial Subject Matter
Badgery's Creek	*		1950	Point sources
Chippindale CSIRO	150.0	34.0	1946	Solar
Culgoora	149.6	30.3	1967	Solar
Dapto	150.8	34.5	1949	Solar spectrum
Dover Heights, Sydney	151.2	33.9	1947	Solar, planetary, galactic, extragalactic
Fleurs	150.8	33.9	1952	Discrete radio sources
Hobart	147.5	42.8	1960	Solar, Jupiter, galaxy
Molonglo	149.4	35.4	1967	Pulsars, Magellanic Clouds, SN remnants
Narrabri	149.8	30.2	1963	Stellar diameters
Parkes	148.3	33.0	1961	Catalogue of radio sources, planets, Milky Way, solar-terrestrial relations, search for extra-terrestrial life
Potts Hill, Sydney	151.0	33.9	1949	Solar rotation, Magellanic Clouds, interstellar hydrogen

**30 mi from Sydney*

The discovery of the 21-cm line inspired the construction of the 210-foot parabolic radio telescope at Parkes, erected in 1961 (Figure 10). At that time Jodrell Bank in the U.K. already had its tremendous 250-foot radio telescope, completed in 1957. The even larger 300-foot at Greenbank, USA, was not completed until 1962, and the fantastically large Arecibo, Puerto Rico radio telescope—a dish in the ground covering 20 acres, diameter 1000ft—was completed in 1963. Contrast these sizes with the largest optical telescopes: the 200-inch Palomar telescope, the largest single-mirror reflector, and the 400-inch multi-mirror Keck telescope in Hawaii, consisting of a mosaic of 36 separate hexagonal mirrors.

Several of the Australian radio telescopes are interferometers spreading over large areas. For example, at Culgoora, used primarily for solar work, 96 separate aerials, each 45 feet in diameter, are spread around a circle of diameter 1.86 miles, circumference about 6 miles. The first Mills Cross at Fleurs, built in 1954, has two intersecting lines of 32 parabolic reflectors each 19 feet in diameter, both branches of the cross being 1250 feet long. In 1967 Mills built a larger cross at Molonglo near Canberra, each branch of the cross a mile long with 40-foot dishes.

John Bolton at Dover Heights with simple Yagi antennas is credited with having been the first, in 1947, successfully to identify discrete radio "point sources" with known optical sources (Bolton 1982; Bowen 1984, pp. 90–92; Kerr 1984, p. 134), his first three being the Crab Nebula, and two peculiar elliptical galaxies, M87 and NGC 5128 (Cygnus A). The supernova remnant at the center of the Crab Nebula was later identified as a pulsar. More than half the 55 pulsars known in 1971 had been discovered at the mile-long radio cross at Molonglo; the most rewarding was the discovery of radio radiation from the variable HU Velorum which led to the inference that pulsars are supernova remnants. Pulsars are believed to be rotating neutron stars. Their periods of variation range from less than a tenth of a second to only a few seconds. The radio astronomers at Parkes are collaborating with F. Drake of the University of California at Santa Cruz in a search for extra-terrestrial life (Holden 1995). This leads one to recall the first discovery of a pulsar by Jocelyn Bell at Cambridge University in 1967 (Hewish *et al.* 1968). The observed pulsations were initially suspected of being signals from extra-terrestrial life. But the quick discovery of three more such sources in distant galaxies made this interpretation appear unlikely. Hope, however, springs eternal.

From July 1969 the Parkes radio telescope was also involved with the Apollo missions, recording the activities of the first astronauts to land on the moon. These varied activities demonstrate that Australia has been an important world leader in radio astronomy.

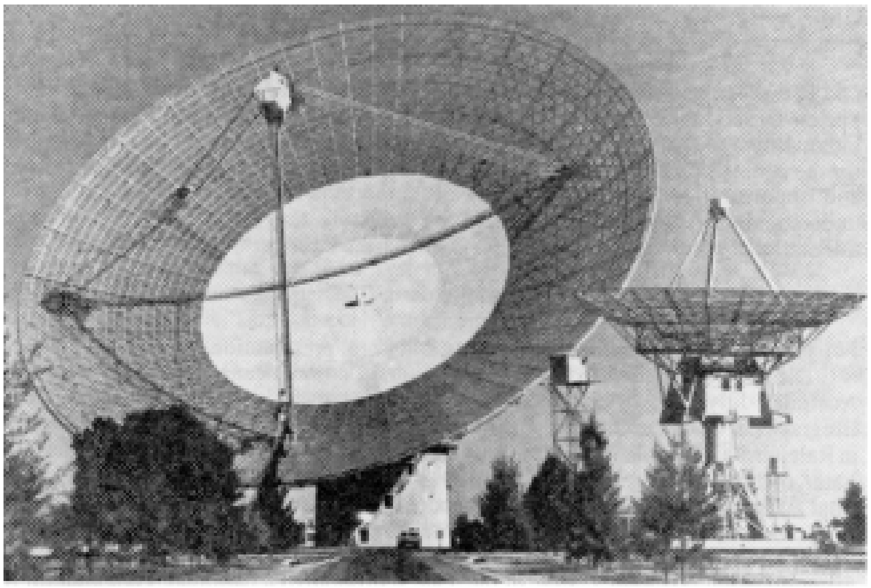

Figure 10. Parkes Radio Observatory.

12. Astronomy and International Fellowship

The International Astronomical Union (IAU) was founded in 1922 largely for the encouragement of international cooperation. At that time, Australia had just four members, one each from Adelaide (G. F. Dodwell), Melbourne (J. M. Baldwin), Perth (H. B. Curlewis), and Sydney (W. E. Cooke). The current IAU directory includes 174 Australian members. This impressive increase may seem small when compared with Russia with 274, Japan 350, United Kingdom 479, France 561, and United States 2069. However, these figures (except for Russia and Japan) are roughly the same proportion of the total populations of these countries (Table 4, based in part on the *World Almanac* for 1996).

The 1973 meeting of the International Astronomical Union was held in Sydney with Harley Wood as host (Irwin 1973). The IAU membership at that time amounted to 3200 astronomers from 47 countries. Of these, 800 members from 39 countries attended the meeting. They were housed in the dormitories of the University of Sydney. The General Assembly was conducted in the first building ever erected at the University of Sydney, then the largest building in Australia in 1859.

Table 4. IAU Members as Fraction of Total Population.

Country	IAU members 1922	IAU members 1994	Increase %	Pop 10^6	Area 10^{6} sq.mi.	Pop/area	IAU/Pop 10^{-6}
Australia	4	174	44	18.1	2.97	6.09	9.6
France	31	561	18	57.8	0.21	275.2	9.7
Japan	8	350	44	125.1	0.15	834.0	2.8
Russia	0	274	–	149.6	6.59	22.7	1.8
UK	30	479	16	58.1	0.09	646.	8.2
USA	53	2069	39	260.7	3.79	68.8	7.9

The accomplishments of astronomers at the modern Mount Stromlo and Siding Spring Observatories and CSIRO clearly put Australia on the map for encouraging international cooperation in astronomy. International cooperation is not only beneficial for the acquisition of data from widely separated localities, but the sharing of insights and opportunities for research is always important for efficiently advancing our understanding of the universe. There are probably few fields of endeavor where international cooperation and friendship have been stronger than in astronomy.

13. Afterword and Acknowledgements

This article is an enlargement of an earlier oral presentation.

The 22nd International Congress on Arts and Communications was held in Sydney, Australia, July 2–9, 1995. The meetings were arranged jointly by the International Biographical Centre in Cambridge, England, and the American Biographical Association in Raleigh, NC. My talk in Sydney inspired the current article on Astronomy in Australia. Later, on March 26, 1996, I gave a similar talk at the New Haven Astronomical Society. That audience encouraged me to go ahead with the current version.

I wish to thank Janet Mattei for accepting this article for publication. Michael Saladyga and Sara Beck have been very helpful in editing and preparing the manuscript for publication. To John T. Lee, of the Yale Astronomy Department, I am grateful for much help and encouragement in the use of my computer as word-processor.

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