

Article

History of Astronomy in Australia: Big-Impact Astronomy from World War II until the Lunar Landing (1945–1969)

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Abstract: Radio astronomy commenced in earnest after World War II, with Australia keenly engaged through the Council for Scientific and Industrial Research. At this juncture, Australia's Commonwealth Solar Observatory expanded its portfolio from primarily studying solar phenomena to conducting stellar and extragalactic research. Subsequently, in the 1950s and 1960s, astronomy gradually became taught and researched in Australian universities. However, most scientific publications from this era of growth and discovery have no country of affiliation in their header information, making it hard to find the Australian astronomy articles from this period. In 2014, we used the then-new Astrophysics Data System (ADS) tool Bumblebee to overcome this challenge and track down the Australian-led astronomy papers published during the quarter of a century after World War II, from 1945 until the lunar landing in 1969. This required knowledge of the research centres and facilities operating at the time, which are briefly summarised herein. Based on citation counts—an objective, universally-used measure of scientific impact—we report on the Australian astronomy articles which had the biggest impact. We have identified the top-ten most-cited papers, and thus also their area of research, from five consecutive time-intervals across that blossoming quarter-century of astronomy. Moreover, we have invested a substantial amount of time researching and providing a small tribute to each of the 62 scientists involved, including several trail-blazing women. Furthermore, we provide an extensive list of references and point out many interesting historical connections and anecdotes.

Keywords: history and philosophy of astronomy; publications; bibliography; obituaries; biographies; sociology of astronomy; instrumentation: miscellaneous; methods: observational; atmospheric effects; Sun: activity; stars: general; (galaxies:) quasars: general

1. Introduction

Inspired by Toner Stevenson's article [1] in the Publications of the Astronomical Society of Australia¹ regarding women's role in constructing Australia's "Astrographic Catalogue" [3], we identify other big-impact astronomy publications from Australia's past while using this as an opportunity to showcase additional women who contributed to the

¹ This followed a (poster) presentation at the Astronomical Society of Australia's Annual General Meeting [2].

legacy of Australian astronomy. For example, while in Sydney from 1890 to 1895, Mary Acworth Orr had recognised the need for a smaller catalogue providing the general public with a more informal guide than the “Astrographic Catalogue”, and she published just such a book in 1896 [4]. Due to demand, this was reprinted in 1911, and Mary Acworth Orr went on to have a career in astronomy, publishing many scientific articles [5].

The period of Australian history that we have focussed on is the quarter of a century after World War II, from 1945 to 1969. This era was a boom time for astronomy. Adding to Australia’s proficiency at observing the heavens at optical wavelengths, it is well known that immediately after World War II, Australia became a world leader in conducting astronomy at radio wavelengths [6–8]. At the same time, Mount Stromlo Observatory, which had produced optical munitions for the war effort, grew into one of the largest optical observatories in the Southern hemisphere. The year 2020 marked the ‘Diamond, gold’ jubilee (75th anniversary) since the end of World War II (1st of September 1939–2nd of September 1945).² Here we investigate and commemorate Australia’s biggest impact astronomy papers and the people who wrote them, from the quarter of a century after this war until the first lunar-landing half a century ago in 1969. As we shall see, this involved scientists from the UK, USA, and elsewhere. To address this objectively, we have split these 25 years into five consecutive time intervals and identified the ten most-cited publications from each interval. This approach helps to negate the growing number of citations with time and allows one to see the evolution in research topics.

As we shall see, over the quarter-century covered, exploration ventured from predominantly studying solar-related phenomena to researching objects far out into space. Indeed, in 1963 the optical counterpart to the radio quasar 3C 273 was determined using lunar eclipsing at the Parkes radio telescope and its cosmological redshift (which was immediately obtained by colleagues in the USA) dramatically and forever changed our understanding of the scale of the Universe. In 1969 the iconic live footage of Neil Armstrong stepping onto the Moon was received at, and sent around the world from, the Honeysuckle Creek radio antenna near Canberra, with the Parkes antenna relaying the latter footage of this historic lunar landing. The famous pulsar paper by Goldreich & Julian was additionally written in 1969 while Goldreich was at the University of Sydney. Continuing Australia’s long tradition of exploring the southern skies, in 1969 we also encounter Lindsey Fairfield Smith, who mapped the positions of many southern Wolf-Rayet stars, and Betty ‘Louise’ Webster, who mapped the positions of numerous southern planetary nebulae around aging stars.³

From this same quarter-century, the most cited astronomy paper from Australia and the world pertains to the “initial mass function” of stars. It was written by E. Salpeter (a refugee from war-torn Europe) while he was at Mount Stromlo Observatory, after having attended high school in Sydney and obtained his B.Sc. and M.Sc. degrees from the University of Sydney. Impressively, Salpeter authored another three highly-ranked articles in our compilation, one of which was with T. Hamada (a postdoc from Japan working on nuclear reactions with Salpeter in Australia just 11 years after World War II had ended via the dropping of nuclear bombs on Japan). J.P. Wild (radio astronomy) and A.E. Ringwood (geophysics & geochemistry, and whose subsequent studies of lunar rocks from the Apollo missions led to the Moon-from-Earth theory) also have several highly-ranked articles spanning the first four and the last three of our five time-intervals, respectively. Australian-based research from other well-known astronomers, such as C.W. Allen, A.R. Sandage, and G.H. de Vaucouleurs, additionally feature here, as does work by Father D.J.K. O’Connell (who went on to become the Director of the Vatican Observatory for 18 years)

² Technically, Britain and France declared a state of war with Germany on the 3rd of September 1939, after Germany had invaded Poland on the 1st of September. The war in Europe ended on the 8th of May 1945, and the war in Asia ended on the 15th of August that year, with a formal surrender by Imperial Japan signed on the 2nd of September 1945.

³ Both Smith and Webster obtained their Ph.D. degrees at Mount Stromlo Observatory during Bart Bok’s directorship, while Bart’s wife Priscilla Bok worked there as a successful and well-respected astronomer. The Bok’s themselves had arrived at Mount Stromlo Observatory after another very prolific astronomy couple, Antoinette and Gérard de Vaucouleurs, who had been there the preceding six years (1951–1957).

and Ronald Bracewell (who is known for his hypothesised alien “Bracewell probes” and his important contributions to radio imaging and medical tomography).

Moreover, several of the astronomers we will encounter had interesting roles during WWII, which may not be well known. For example, optical astronomers in Australia were asked to design and construct optical munitions (‘Walter’ Stibbs, ‘Ben’ Gascoigne), while the proto-(radio astronomers) established early-warning radar which detected and prevented Japanese bombing raids over Australia (Jack H. Piddington, Ruby Payne-Scott, with significant contributions from other notable women such as Joan Freeman and Rachel E.B. Makinson). Their stories, touched on within this article (and with references to further information), tempt one to draw parallels with the recent movie “The Imitation Game”, and makes one wonder if Australia may have its own movie waiting to be made.

In Section 2, we describe the methodology adopted to find the high-impact Australian astronomy articles from 1945 to 1969. This involved knowledge of the facilities that were operational at the time. In Section 3, we tabulate the ten most popular articles from each of our five time-intervals over the quarter of a century from 1945 to 1969. While the titles of the articles are (usually) self-explanatory, and one may wish to merely peruse the tables herein, we have also gone to considerable effort to provide a paragraph or two about the authors of these articles that have had a significant and enduring impact. A concluding summary reflecting on the astronomers, including the female astronomers encountered herein, their work, and the facilities which enabled much of that work, is provided in Section 4, along with connections to the present.

This project was a substantial undertaking and hopefully represents a detailed yet concise, unbiased view of Australia’s astronomical endeavours during the quarter-century after World War II, which have had the biggest impact in the scientific literature. By its nature, it is, of course, not a complete picture of Australia’s astronomical activities during this time, and readers may enjoy delving further into the topic through the many enjoyable books we have listed in Appendix A.

2. Methodology

Identifying the Australian articles was a rather time-consuming task. Many of the older articles have no address in their header information, and thus there is no ‘affiliation tag’⁴ upon which to search for the keyword “Australia”. However, thanks to the availability of scanned articles in the Smithsonian Astrophysical Observatory’s “Astrophysics Data System” (ADS)⁵ now stretching back decades and centuries, coupled with their text recognition software and advanced web-based query form, investigations such as ours have become possible. In particular, the “ADSLabs Full Integrated Search” (which became “Bumblebee” in mid-2015 and the “User Interface” in 2018) had recently, in 2013, opened up a new frontier for historical research by enabling one to instantly search the full text of scanned articles dating back to well before Australia was reached by the British in 1770. It should be noted that while this wonderful new system is adequate for our objective, as with all bibliographic databases, the ADS is not 100% complete⁶, and it becomes increasingly less so the further back in time one samples. Indeed, the citations record is grossly incomplete during and before World War II (1939–1945), and as such, it is not easy to obtain useful/complete quantitative information from before 1945.

As noted above and in Section 2 of Hearnshaw [9], a critical issue that needed overcoming was identifying the Australian research papers. In the past, authors would simply include their name and a very brief address at the end of their article. Moreover, this ‘signature’ information is not stored neatly in ADS. If it was, we could have quickly found the Australian-led papers in ADS with the ‘affiliation position’ search command: `pos(aff:Australia,1)`. One could then include the years of interest, and with the click of

⁴ The affiliation tag, which appears at the top of articles today, identifies the author with a place and country of work.

⁵ <http://adsabs.harvard.edu> (accessed 15 February 2015).

⁶ http://doc.adsabs.harvard.edu/abs_doc/faq.html#complete (accessed 15 February 2015).

a button, rank the results according to how many citations they had accrued. However, given that Australian articles did not always include the word “Australia”, we needed to uncover a set of keywords that authors did use to identify their place of work, and we do that in this section. ADS then automatically searched through the full text of the scanned articles looking for these keywords pertaining to Australian places and facilities. We then manually checked the papers found by ADS to confirm/deny their Australian heritage. For example, references to Australian eclipses or someone else’s work in a named part of Australia do not just appear in Australian articles, consequently requiring us to filter those out. This contamination made our task somewhat laborious but possible by individually inspecting the most well-cited papers to check if they were affiliated with Australia.

As for the journals, in 1947, the Monthly Notices of the Royal Astronomical Society (MNRAS) introduced the REFERENCE section at the end of their articles, abandoning the previous (and often vague) footnote referencing style on individual pages. The scientific journals Nature, Science and The Astronomical Journal (AJ) were already using this format before 1945, and it was later adopted by CSIRO’s Australian Journal of Scientific Research A (AuSRA: 1948–1952) and CSIRO’s Australian Journal of Physics (AuJPh: 1953–2001). However, the The Astrophysical Journal (ApJ) did not start doing this until 1954, the year that the ApJ Supplement began publication. As such, citations given in ApJ articles published before 1954 are typically not included in ADS. For reference, we note that the European journal Astronomy and Astrophysics did not commence until 1969, two years after the Publications of the Astronomical Society of Australia (PASA) began.

It should be recognised that (pre-internet) papers in Australian journals, without the same worldly distribution as some other journals, would have had a smaller global reach and thus a lower impact. Similarly, the Australian Journal of Physics likely had a smaller astronomy audience than the mainstream astronomy journals commanded. Therefore, an understandable CSIRO policy to support and grow the local journals may have restricted CSIRO research’s impact if these journals were not distributed widely. Additionally, like X-ray astronomy in the late 1960s (e.g., [10,11]), radio astronomy in the late 1940s was a new field of research and would have had a smaller group of participants than optical astronomy. It would, however, give rise to over 20 field stations in the 1950s and 1960s, and today many astronomers continue to use and cite the early radio astronomy publications, over-coming the early participation-bias and thereby generating a broad impact. This ongoing trend, bolstered by a new wave of radio astronomers, is evident in Appendix B.

From 1945 to 1969, we split the period into five time-intervals. To help nullify or offset the increased number of publications and citations over the years (for example, [12]), we searched within a 6-year interval (1945–1950), three 5-year intervals (1951–1955, 1956–1960, 1961–1965) and then within a 4-year interval (1966–1969). We identified the ten most-cited articles within these five time periods, with the final citation data collected in February 2015. As such, we may have captured some articles that were ahead of their time and not immediately well-cited, and we may have avoided articles that were a flash-in-the-pan and not sustained by a long period of citation.

2.1. Post WWII Observing Facilities

In what follows, we identify Australia’s main astronomical observing facilities from 1945 to 1969. Besides simply listing them in Table 1, we provide a brief historical context for each, as this helps in part to better connect them with the research and researchers whom we later identify.

Table 1. Post 1945 Keywords used for full-text search in ADS.

Keyword	Associated Place(s)
Commonwealth Solar Observatory	Mount Stromlo Observatory (1924–1950)
Commonwealth Observatory	Mount Stromlo Observatory (1950–1957)
Mount Stromlo	Mount Stromlo Observatory (1957–)
Australian National University	The Australian National University (1946–)
Uppsala Southern Station	Mount Stromlo Observatory (1957–1982)
Yale–Columbia Southern Station	Mount Stromlo Observatory (1952–1992, burnt in 2003)
Mount Bingar	Mount Bingar field station, N.S.W. (1959–1962)
Siding Spring	Siding Spring Observatory, N.S.W. (1964–)
CSIR	Council for Scientific and Industrial Research (1926–1949)
CSIRO	Commonwealth Scientific and Industrial Research Organization (1949–)
Chippendale	National Standards Laboratory (1939–1973) Division of Radiophysics HQ, (Sydney) University Grounds (1939–1968) Division of Physics HQ (1945–1973)
Dover Heights	Division of Radiophysics, key field station (1946–1954)
Georges Heights	Division of Radiophysics, Middle Head, Sydney (1947–1948)
Hornsby Valley	Division of Radiophysics, (1947–1952)
Potts Hill	Division of Radiophysics, key field station (1948–1962)
Penrith	Division of Radiophysics, (1949–1950)
Badgery’s Creek	Division of Radiophysics, on a cattle research station (1949–1956)
Murraybank	Division of Radiophysics, Orchard of astronomer John Murray (1956–1961)
Dapto	Division of Radiophysics, Dapto Dairy’s Radio Spectrograph (1952–1965)
Culgoora OR Narrabri	Division of Radiophysics, Culgoora Solar Observatory and Radio Heliograph at the Paul Wild Observatory (1967–1984)
Parkes	Parkes Observatory (1961–)
Molonglo	Molonglo Radio Observatory (1965–)
Buckland	Buckland Park Aerial Array (1969–)
Riverview	Saint Ignatius’ College; Riverview College Observatory (1909–)
N.S.W. OR New South Wales	Many
Sydney	Sydney Observatory; Sydney University Grounds; etc.
Canberra	Mount Stromlo Observatory; The Australian National University
Melbourne	Melbourne Observatory; The University of Melbourne
Adelaide	Adelaide Observatory; The University of Adelaide
Perth OR Western Australia	The Univ. of Western Australia; Perth Observatory
Hobart OR Tasmania	The Univ. of Tasmania; Comm. Obs. Ionospheric Prediction Service
Brisbane OR Queensland	The University of Queensland
Darwin	RAAF Radar Station 59

2.1.1. Mount Stromlo Observatory

By the start of the 20th century, astronomers around the world were very interested in the sunspot cycle, the structure of the convection zone, solar flares, and the heating of the outer layers of the Sun. However, they realised how little they knew about the Sun. Starting in 1905, Walter G. Duffield (1879–1929), from Adelaide but at the time undertaking an M.Sc. at the University of Manchester in the United Kingdom, campaigned to establish a **Commonwealth Solar Observatory** in Australia [13,14]. Once it was eventually approved, he helped ensure that it would be incorporated into the plans for the new Australian Capital Territory (ACT). To his credit, in 1911, the very first Commonwealth building⁷ in the new Australian Capital Territory had a dome at one end: it housed the donated 9-inch

⁷ This building would also later serve as a quiet office for Ph.D. students, such as Ronald (Ron) David Ekers (b.1941), who obtained his Ph.D. from The ANU in 1967 before going on to become the Director of the Very Large Array, in New Mexico, from 1980 to 1987, and the Director of the Australia Telescope National Facility (1988–2003).

Oddie Telescope⁸ to test Mount Stromlo’s suitability and “seeing” conditions. Although the site checked out⁹, due to delays, including World War I, the Commonwealth Solar Observatory did not ‘open’ until 1924, 13 years after the Oddie Telescope had been erected there. In that year, British engineer and amateur astronomer, J.H. Reynolds donated a 30-inch reflector, following on from Lord Farnham’s 1914 donation of a 6-inch refractor. Even then, from late 1924 to 1926, the founding Director, W.G. Duffield—who had been at the University of Reading in the UK from 1910 to 1923—was based in what is now the main bar of the Hotel Canberra. He had to wait until the buildings on Mount Stromlo were finally fit for occupancy.

During WWII, the Commonwealth Solar Observatory converted their workshop¹⁰ into something of a factory to produce ‘gun sights’, and prisms for binoculars, telescopes, and periscopes for the military campaign. After WWII, the Commonwealth Solar Observatory switched from just solar and atmospheric observations (for example, [16–19]) to stellar and galactic work.¹¹ In 1944, the Victorian State Government closed the Melbourne Observatory—parts of which became a psychiatric clinic—and in 1945, the Commonwealth Solar Observatory in Canberra became the **Commonwealth Observatory**, having purchased in 1944 the Great Melbourne telescope (which had effectively been obsolete since the 1890s, Hogg [20]).¹² The Commonwealth Observatory grew to become one of the largest optical observatories in the Southern Hemisphere from 1945 to 1969. As such, it attracted and produced many of the world’s best observers at that time. The observatory’s 74-inch optical telescope (1955–2003) was a replica of the 74-inch telescope built by the British in Pretoria, and as such, it was the equal second-largest optical telescope in the Southern hemisphere from 1955 to 1974. **The Australian National University (ANU)** opened in 1946, and in 1957 the observatory became known as **Mount Stromlo Observatory**, officially transitioning from the Commonwealth Department of the Interior to become a part of The ANU.

In searching for the location of a new dark-sky site, in 1957, Mount Stromlo Observatory staff, together with Isadore Epstein from Yale University (she was funded by the US National Science Foundation to find a new site in Australia), searched as far south as Horsham, just north of the Victorian Grampians, and as far west as Geraldton in Western Australia. While travelling with Harley Wood¹³, Ben Gascoigne¹⁴, and Richard Twiss (who was looking for a site for a new optical interferometer for The University of Sydney), Epstein inspected **Siding Spring Mountain**¹⁵ in 1957. In 1962 the site was chosen, edging out **Mount Bingar**¹⁶ in the district of Griffith, and it officially opened in 1965. While The ANU owns **Siding Spring Observatory**, several telescope sites are leased to other organisations, such as the Australian Astronomical Observatory (formerly the Anglo Australian Observatory). The Anglo Australian Telescope (AAT) keywords were, however, not required because the AAT did not open at Siding Spring Observatory until 1974. It was co-funded by the British, thanks largely to Richard vdr. Woolley, former Director of Mount Stromlo Observatory and at that time the Astronomer Royal in England. Similarly, the Royal Observatory of Edinburgh’s 1.2 m UK Schmidt telescope at Siding Spring Observatory did not commence operations until 1973; it was handed over to the Anglo Australian Observatory in 1988.

⁸ In 1910, **James Oddie** (1824–1911) donated an excellent 9-inch refracting telescope which he had imported from Thomas Grubb of Dublin and kept in its box since 1888.

⁹ Victorian Government astronomer **Pietro P.G.E. Baracchi** (1851–1926) and J.M. Baldwin reported that Mount Stromlo never had less than 4 fine nights out of 7, after week-long samples taken every month over a year.

¹⁰ A bushfire destroyed the workshop in February 1952 [15], and another bushfire destroyed the re-built workshop in January 2003.

¹¹ Over the ensuing years, much of Australia’s solar and meteorological research steadily transitioned to the Commonwealth Scientific and Industrial Research Organisation (CSIRO).

¹² Hogg [20] outlined the historical development of optical observatories in Australia.

¹³ The first President of the Astronomical Society of Australia (ASA).

¹⁴ The first Vice-President of the ASA.

¹⁵ Furthermore, known as Mount Woorat.

¹⁶ From 1959 to 1962, The ANU had a ‘field station’ on Mount Bingar, with a 26-inch reflector used for photoelectric photometry.

Foreign-funded facilities in Australia were nothing new, and naturally the British still had an interest in (supporting) astronomy from Australia after Australia became a Federation in 1901. In addition, due to the Swedish astronomer Karl Gunnar Malmquist (1893–1982: Elvius [21], who is known for “Malmquist bias” [22,23], the University of Uppsala had located a 0.65 m reflecting telescope at the Commonwealth Observatory in Canberra for their **Uppsala Southern Station**. The Yale and Columbia Universities had also previously relocated their enormously-long **Yale-Columbia** 26-inch refractor from Johannesburg, South Africa, to the Commonwealth Observatory to continue their campaign of southern stellar parallaxes. Their interest in 1957 pertained to installing a 20-inch astrograph at a better site.

2.1.2. University of Sydney

In June 1940, physics departments around Australia were asked to assist in the war effort. At the University of Sydney, Rachel E.B. Makinson, born Kathleen Rachel White in London (1917–2014: McCarthy [24]), had just arrived before the war with a Double First Bachelor degree in Physics from Cambridge. She had also just married Richard (Dick) Makinson¹⁷, an Australian physicist whom she met at Cambridge. If not for the war (with so many men away fighting overseas), she may well have struggled to find employment because of her marital status. However, Professor Victor A. Bailey took her on as a research assistant at the University of Sydney, where she tutored radio physics to RAAF airmen and others (known as the “Bailey Boys”, [25]) involved in secret radar work within the radiophysics lab [26–30]. Many of them went on to become Australia’s first radio astronomers. After the war, the University of Sydney would not offer R. Makinson a permanent job in the physics department because her husband had one there. In fact, for 20 years after the war, she worked for the **Council for Scientific and Industrial Research** (CSIR, 1926–1949), later known as the **Commonwealth Scientific and Industrial Research Organisation** (CSIRO, 1949–), on annual contracts because married women were denied permanent positions. She studied the physics of wool fibres until she was finally granted a permanent position. She became CSIRO’s first female Chief Research Scientist in 1977 and the first female Assistant Chief of the Division of Textile Physics (1979–1982).¹⁸

Having headquartered CSIRO’s Division of Radiophysics and their Division of Physics—and trained many of their staff—The University of Sydney was well placed to expand into astronomy and astrophysics. Their Astrophysics Department was formed in 1962 and charged with building the **Molonglo Radio Observatory**. Headed by B.Y. Mills, it subsequently opened in November 1965. Primarily funded by the USA National Science Foundation (USD \$846,000 initially, and later US \$107,500 extra), the radio telescope originally had cross-shaped arms 12-metres-wide by one-mile-long. In addition to this grand venture, in 1961, the Chatterton¹⁹ Astronomy Department was established within the School of Physics at the University of Sydney. It was co-located in the same building and floor as the Astrophysics Department. The Astronomy Department would commission and operate the **Narrabri Stellar Intensity Interferometer**. R. Hanbury Brown and R.Q. Twiss had come to Sydney in 1962 from the University of Manchester, with Hanbury Brown leading this new department. He and Twiss had previously built an optical intensity

¹⁷ Richard Makinson (1913–1979) was a member of the Communist Party of Australia (CPA) whose physics career suffered once identified as a member. Not surprisingly, ASIO also kept close surveillance on Rachel Makinson.

¹⁸ A pioneer of Australian science in more ways than one, R. Makinson has a connection with the coloniser Elizabeth Macarthur who studied astronomy in Sydney with the First Fleet’s official astronomer Lieutenant William Dawes. (Lieutenant Dawes’ son, born William Rutter Dawes in England, is himself well known for “Dawes limit”). Together with her husband, Elizabeth and John Macarthur are largely responsible for establishing the wool industry in Australia (including Tasmania); indeed, for 8 years, Elizabeth managed the merino flocks in Sydney while her husband was overseas.

¹⁹ Stanley Chatterton, one of the five founders of Woolworths in Australia, provided a grant of 50,000 pounds which enabled Prof. Harry Messel, Head of the School of Physics since 1952, to establish the new Astronomy Department. By this time, Messel had raised more than £3M for the School of Physics, with more than £2 M from overseas. The School’s ‘theoretical physics’ department, for example, was named after Sir ‘Frank’ Packer (1906–1974), the media magnate, father of Kerry F.B. Packer (1937–2005) and grandfather of James D. Packer (1967–). Given the Fairfax family’s prior connections with astronomy, encompassing the 1874 transit of Venus and friendship with George D. Hirst (1846–1915: [31]), it is perhaps surprising that the Astrophysics Department was not supported by and thus named after the Fairfax family—although one may speculate that Messel likely tried. In 1872, John Fairfax established the Fairfax Prize for the greatest proficiency among the female candidates of the Junior and Senior Public Examinations for matriculation honours and certificates—effectively providing two student scholarships to The University of Sydney.

interferometer in the UK, but the cloudy UK weather meant it was hard to acquire data. The University of Manchester, together with the University of Sydney's School of Physics, therefore co-funded the installation and maintenance of the Narrabri Stellar Intensity Interferometer.

2.1.3. CSIRO

During and after WWII, the CSIR's and CSIRO's **Division of Radiophysics**, and the Australian Postmaster General (PMG) Research Laboratories (now Telstra) developed more than 20 different radar systems or 'field stations'. While too numerous to describe here, most are listed in Table 1 or Section 2.1.7, with more detailed discussions found in Sullivan [8], Wendt and Orchiston [32], and other references listed in Appendix A. The Division of Radiophysics (not to be confused with the **Division of Physics**, which also conducted astronomical work and was similarly headquartered on the **University of Sydney Grounds** in Chippendale) commenced their radio astronomy research programs in 1945. Ron Giovanelli led one group that built a solar optical observatory at **Culgoora** in New South Wales, while Paul Wild led the group that built a solar radioheliograph there. CSIRO's Division of Radiophysics had also received a £0.63 M grant from the Ford Foundation of America to pay for half the radioheliograph cost, which opened in 1968 with CSIRO paying for the land. Radio astronomy was booming in the 1960s. Construction of the **Parkes radio telescope**²⁰ was 50% paid for by the US-based Carnegie Corporation (USD \$250 k) and the Rockefeller Foundation (USD \$380 k) with the Australian Government contributing the remaining 50% and operational costs [33]. The telescope is, of course, located in the regional NSW town called Parkes, named after Sir Henry Parkes (1815–1896), the "Father of Federation" who appears on the Centenary of Federation commemorative AUD \$5 note (issued in 2001), on the AUD \$1 coin from 1996, and a 3 pence Australian postage stamp from 1951 (for the Golden Jubilee). The Parkes telescope featured on the first AUD \$50 note (along with other astronomy-related images), and on an Australia Post stamp from 1986 (in connection with Comet Halley), and also on an AUD \$1 coin from 2009 (issued to celebrate the International Year of Astronomy by the Royal Australian Mint, marking 400 years since Galileo used a telescope in 1609 to observe the heavens). In 1988 the Culgoora radioheliograph was replaced by the Australia Telescope Compact Array ATCA of radio antennas. In an unusual break from tradition, this was fully-funded by the Australian Government (AUD\$50 million). This was perhaps achieved because the project was badged successfully as an official Bicentennial project celebrating the 200th anniversary of European colonisation in Australia, which had its origins in astronomical endeavours. Spending only 20% of the funds offshore and calling it the *Australia Telescope* also likely helped its cause, although one would be forgiven for expecting to have seen a collaboration with, and contribution from, the British and/or Americans.

2.1.4. The University of Adelaide

By 1969 the Department of Physics at The University of Adelaide had developed the **Buckland Park Aerial Array**²¹ [34]. Some 40 km north of Adelaide and 1 km square in size, it was built for studying the ionosphere, including its drift overhead, and meteors²². The Buckland Park Research Station's air shower array, built to detect radio and Cerenkov emission from high energy cosmic ray showers in our atmosphere, commenced operations in 1972. As with the AAT and ATCA, this facility came online post-1969.

The University of Adelaide and the Weapons Research Establishment (WRE) at Salisbury used rockets and satellites to observe the Sun at UV and X-ray wavelengths. The University of Adelaide also worked with The University of Tasmania to conduct X-ray astronomy in the late 1960s using sounding rockets and balloon payloads.

²⁰ The telescope recently received a traditional Indigenous name, 'Murriyang', representing the 'skyworld' where a prominent creator spirit is said to live.

²¹ <http://www.physics.adelaide.edu.au/atmospheric/facilities.htm> (accessed 29 March 2021).

²² The disturbing effects of meteors on the ionosphere and thus long radio transmissions were first noted in Japan [35] and studied in the 1930s [e.g., [36–38], and references therein]. Radar would later detect aircraft, meteors, and missiles.

Due to our focus on astronomy, we do not include Australia's military involvement in space which began in 1946 through the establishment of an Anglo-Australian Joint Project, which resulted in Australia becoming the 4th nation in the world to place a satellite into orbit from home soil on the 29th of November 1967. Over the dozen or so years before the launch of WRESAT, the Project employed thousands of people in Woomera. WRESAT contained a suite of instruments designed and built by the former Department of Supply's WRE, together with The University of Adelaide, to probe, among other things, Earth's upper atmosphere and the temperature of the Sun's corona.

2.1.5. The University of Tasmania

Grote Reber (1911–2002: Peratt [39], Tyson [40], Kellermann [41,42] moved from the USA to Tasmania in 1954 to observe the southern skies (the centre of the Milky Way) and determine the lowest radio frequencies that one could observe [43,44]. Together with Graeme R.A. 'Bil' Ellis (1921–2011: Delbourgo and McCulloch [45] from the Ionospheric Prediction Service in Tasmania²³, they built a receiver the following year which operated at frequencies as low as 0.52 MHz. In the 1960s, Reber built another telescope, and The University of Tasmania constructed several others, including the 609 m × 609 m Llanherne Low-Frequency Array [46] near Hobart's Llanherne Airport. Construction on this started in 1967, but it did not become fully operational until 1972.

2.1.6. Monash University

The Mount Burnett Observatory²⁴ did not commence operations until the 1970s and was thus not included in our search.

2.1.7. Other

The following keywords were additionally checked, but this did not yield any previously missed articles: Fleurs²⁵, including the Fleurs Synthesis Telescope; Cumberland Park; Rodney Reserve; Freeman's Reach; Llandilo; Rossmore; Seacliff Observatory; Long Reef; Wallacia; North Head; West Head; Collaroy; Llanherne; Bothwell; Kempton; and Penna. In addition to the early radar stations, we checked for publications from Australian-based Tracking Stations, such as Honeysuckle Creek (1967–1981), Tidbinbilla (1965–), Island Lagoon, Muchea, Carnarvon, Cooby Creek, and Orroral Valley.²⁶

3. The Publications and the People

In this Section, five tables display the top-ten Australian publications from five sequential time intervals. In the first table (1945–1950), we increased this count to show the top-15 publications. Doing so allowed us to capture additional interesting material from the earlier years in our study.

In terms of world-ranking, as opposed to the Australian-ranking shown in the first column of the tables, the articles are among the top 1 to 2 percent most cited astronomy publications from their respective era. Over the years 1945–1950, 1951–1955, 1956–1960, 1961–1965 and 1965–1969, the ADS records a total of 13,765, 12,487, 17,536, 30,577 and 41,220 astronomy-related bibliographical sources. To a good approximation, the first half of the articles appearing in Tables 2–5 are ranked in the top 1 percent globally, while all of the articles appearing in Table 6 (1966–1969) are ranked in the top 1 percent. Of particular note is the first entry in Table 3, ranked number one in the world, and the first entry in Table 6, ranked number five in the world, from their respective eras.

²³ The IPS was headquartered at the Commonwealth Observatory in Canberra.

²⁴ <https://mbo.org.au/> (accessed 29 March 2021).

²⁵ The 18 m dish at Fleurs, a key field station near Badgery's Creek (1954–1963), was referred to as the 'Kennedy Dish'. It was relocated to Parkes and formed a part of the Parkes Interferometer [47].

²⁶ In 1986, the 26 m satellite-tracking telescope at Orroral Valley near Canberra was given to the University of Tasmania.

3.1. 1945–1950

As seen in Table 2, studies related to the Sun dominate the popular articles from 1945 to 1950. Below we provide information about the scientists who researched and wrote these articles.

Sydney-born **Douglas ‘Walter’ Noble Stibbs** (1919–2010: Lloyd Evans [48], Stickland [49]) obtained the 1942 University of Sydney Medal in physics for his B.Sc. Honours degree, before obtaining in 1943 his M.Sc. degree and becoming an elected Fellow of the Royal Astronomical Society that same year. During this time, he worked at Mount Stromlo’s Commonwealth Observatory, designing a folded optical system for gunsights and a sun-compass for desert navigation (both of which were used during the War). In 1950, before leaving the Commonwealth Observatory in 1951, he wrote the influential paper [50] explaining the variable magnetic star HD 125,248²⁷, which is Australia’s most-cited astronomy-paper from 1945 to 1950. HD 125,248 reverses its magnetic field every 9.3 days, with the radial velocity of the star’s elements moving in synchronisation with this. As the elements move outward along lines of magnetic force, their flow velocity responds according to the magnetic field strength. Stibbs [52] wrote an accompanying Letter to Nature explaining this phenomenon. He then spent time at Oxford and worked in South Africa on the radial velocities of southern cepheids for tracing Galactic rotation [53,54]—research which earned him his Ph.D. Stibbs is, however, perhaps best known as the Napier Professor of Astronomy and Director of the Observatory at the University of St. Andrews, Scotland (1959–1989), where he introduced the largest computer in Europe in 1961. Upon retiring, he spent the next 20-odd years as a ‘Visiting Fellow’ back at Mount Stromlo Observatory and The ANU’s Mathematical Sciences Institute, giving occasional lectures in statistical methods, and since 2013 he is remembered through the “Professor Walter Stibbs Lectures” organised by the University of Sydney.

In 1929, Scottish-born **David Forbes Martyn** (1906–1970: Piddington [55], Piddington and Oliphant [56]) came from Imperial College London to join the Australian Radio Research Board (now the Australian Telecommunications and Electronics Research Board). A part of the CSIR at the University of Melbourne, the Board was established in 1927 to improve Australia’s radio procedures [57]. In 1932, Martyn transferred to the Board’s group at the University of Sydney, which was directed by Sir John Percival Vissing Madson (1879–1969: White [58]). Martyn helped Australia’s broadcasting services with their radio transmissions while also studying the Earth’s ionosphere. Martyn is known for “Martyn’s theorem” regarding the attenuation of radio waves [59] and the “Bailey-Martyn Theory” [60] which solved the mystery of the “Luxembourg effect”.²⁸ In 1939, Martyn was on the short-list—along with Subrahmanyan Chandrasekhar (1910–1995, co-recipient of the 1983 Nobel Prize for Physics)—for the Directorship of the Commonwealth Solar Observatory in Canberra. This position was ultimately awarded to R. Woolley (see later). In February 1939, Martyn was invited by the British Government to spend six months in England learning the secrets of radar. The Australian Prime Minister Lyons had, at the time, been asked by the Australian High Commission in London to send the best-qualified physicist for a secret mission concerning radar. When Martyn returned to Australia, he was made the Chief of the CSIR’s new Radiophysics Division and Laboratory, back at the University of Sydney, for secret WWII radio direction finding and distance-ranging [29,61–63]. Martyn did, however, eventually move to the Commonwealth Solar Observatory at the end of 1944. In 1947, he published his award-winning modified dynamo theory connecting the Earth’s magnetic field with its ionised atmosphere and the influence of solar and lunar tides [64,65]. He successfully expanded this research into the 1950s with three more articles [66–68], see Table 3. Sadly, after much service to Australia, including President of the Australian

²⁷ The original Henry Draper (HD) Catalogue contained spectra from, and classifications for, 225,300 stars. HD 125,248 (CS Virginis; BD-18 3789), the variable star of α^2 CVn type, was included in the 1920 volume [51] by Annie Jump Cannon and Edward Charles Pickering, with the spectra obtained from the Bache Telescope, mounted at Arequipa, in Peru.

²⁸ In England, a Luxembourg radio station playing popular music could be heard intermittently between the BBC’s stronger signals. The modulation of a passing radio signal by a powerful intervening source had some relevance for the war effort regarding the jamming of (an enemy’s) radio signals.

Academy of Science (1969–1970), and starting the Radiophysics Division which developed Australia’s radar surveillance during WWII, he was given electric shock ‘treatment’ for a mental illness and eventually committed suicide in 1970.

John Paul Wild (1923–2008: Garrett [69], Frater and Ekers [70], Frater et al. [71]) was born in Sheffield, England. A gunnery and radar officer in the Royal Navy (1943–1947), he was also involved in research trying to understand why early radar was sometimes jammed, later found to be due to radio interference from the active Sun²⁹. Wild became a CSIR radio astronomer in 1947, working for L.L. McCready (mentioned below) in building a radio-spectrograph. Using this to monitor the emission of solar bursts from 70 to 130 MHz, in 1950, they classified three types of spectral burst [75–77]. Over the ensuing years, the frequency coverage and technological complexity of their radio-spectrographs were steadily increased. Wild subsequently worked his way up the ranks and became chief of CSIRO’s Division of Radiophysics in 1971 and then chairman of CSIRO from 1978 to 1985. His team built the 3 km diameter Culgoora radioheliograph (1967–1982), producing spatially-resolved, real-time images of activity in the Sun’s corona. The “Paul Wild Observatory” at Culgoora, now home to the Australia Telescope Compact Array, the Sydney University Stellar Interferometer, a node of the Birmingham Solar Oscillations Network, and the Ionospheric Prediction Service³⁰, is named in his honour.

Further afield, during the 1970s, Wild received financial support from the Commonwealth Department of Transport for the “Interscan” microwave landing system (MLS) for aircraft. However, the global positioning system (GPS) was ultimately preferred by the International Civil Aviation Organisation. During the years 1986–1991, immediately after Wild had resigned from CSIRO, he tried to establish the “Very Fast Train joint venture”. After failed talks with the NSW State Rail Authority, this was to be a privately-run, high-speed railway between Melbourne-Canberra-Sydney. Somewhat unrelated, but of interest, is that during WWII, just after Wild arrived at CSIR, the NSW Government Railway³¹ had been constructing (Radiophysics Laboratory)-designed aerials and transmitters/receivers for radar detection. J.G. Worledge engineered these at the Eveleigh workshops—where many indigenous Australians had been working for the war effort.

While working with J.P. Wild, J.L. Pawsey, R. Payne-Scott, and others, **Lindsay Leslie McCready** (1910–1976), from Leeton, New South Wales (NSW), led much of the engineering effort at CSIR(O). This was due in part to his previous employment with Amalgamated Wireless (Australasia). In so doing, he helped the budding astronomers observe a correlation between sunspot coverage and radio noise, and they also deduced that the temperature of the Sun [or rather its corona] is far over 6000 degrees and as high as one million degrees [78–80].

Noted below, Pawsey and Payne-Scott developed radio interferometry in 1946 (as did the British radio astronomers Martin Ryle³² and Derek Vonberg³³) to enable higher resolution imagery. The first use for astronomy was by McCready, Pawsey & Payne-Scott using the single dish (WWII radar antenna) sea-cliff interferometer in Sydney. This built on the unpublished, classified work of J.C. Jaeger (1907–1979: Paterson [81]) in 1943 to determine the elevations of incoming aircraft [82] (p. 277). They did this using reflections of the Sun, at sunrise, off the sea which acted as a reflecting surface to produce the interference pattern, akin to the well-known Lloyd’s mirror interferometer [83].

²⁹ In 1942, James Stanley Hey (1909-2000) recognised the cause was due to sunspots and solar flares [72,73], as did George Clark Southworth (1890–1972: [74]) at the Bell Telephone Laboratories.

³⁰ <http://www.ips.gov.au/> (accessed 29 March 2021).

³¹ Curiously, prior to becoming the first President of the Astronomical Society of Victoria, Charles J. Merfield (1866–1931) from Ararat, Victoria, had distinguished himself with the Victorian and NSW State Rail Authority for his mathematical knowledge of track laying.

³² M. Ryle (1918–1984), a founding father of radio astronomy, shared the 1974 Nobel Prize in Physics with Antony Hewish (1924–) for their pioneering radioastrophysics research.

³³ D. Vonberg (1921–2015) became a medical research scientist.

Table 2. The ten most cited articles from 1945 to 1950 are numbered in column 1, and involve ten distinct authors.

#	Title	Affiliation	Author(s)	Year	Journal Vol. Page	Cites
1.	A study of the spectrum and magnetic variable star HD 125248	MSO	Stibbs, D.W.N.	1950a	MNRAS 110, 395	(251)
2.	Atmospheric Tides in the Ionosphere. I. Solar Tides in the F ₂ Region	CSIR-Radiophysics & MSO	Martyn, D.F.	1947a	RSPSA 189, 241	(134)
3.	... Spectrum of High-Intensity Solar Radiation at Metre Wavelengths. III. Isolated Bursts	CSIRO-Radiophysics	Wild, J.P.	1950b	AuSRA 3, 541	(126)
4.	Magnetic and Electric Phenomena in the Sun's Atmosphere associated with Sunspots	CSIR - Physics	Giovanelli, R.G.	1947	MNRAS 107, 338	(103)
5.	A Theory of Chromospheric Flares	CSIR - Physics	Giovanelli, R.G.	1946	Nature 158, 81	(101)
6.	Observations of the Spectrum... I. The Apparatus and Spectral Types of Solar Burst Observed	CSIRO-Radiophysics	Wild, J.P. & McCready, L.L.	1950	AuSRA 3, 387	(100)
7.	Interpretation of Electron Densities from Corona Brightness	MSO	Allen, C.W.	1947	MNRAS 107, 426	(97)
8.	Positions of Three Discrete Sources of Galactic Radio-Frequency Radiation	CSIRO-Radiophysics	Bolton, J.G., & Stanley, G.J. & Slee, O.B.	1949	Nature 164, 101	(92)
9.	The Coronal Emission Spectrum	MSO	Woolley, R.D.V.R. & Allen, C.W.	1948	MNRAS 108, 292	(72)
10.	Atmospheric Tides ... II. Lunar Tidal Variations in the F Region Near the Magnetic Equator	CSIR-Radiophysics & MSO	Martyn, D.F.	1947b	RSPSA 190, 273	(63)
Extending the list to the 15 most cited articles from 1945 to 1950 involves 15 distinct authors.						
11.	Observations [] at Metre Wavelengths. II. Outbursts	CSIRO-Radiophysics	Wild, J.P.	1950a	AuSRA 3, 399	(55)
11.	The spectrum of the Corona at the eclipse of 1940 October 1	MSO	Allen, C.W.	1946	MNRAS 106, 137	(55)
12.	Radio-Frequency Radiation from the Quiet Sun	CSIRO-Radiophysics	Smerd, S.F.	1950	AuSRA 3, 34	(54)
12.	Solar Radiation at Radio Frequencies and Its Relation to Sunspots	CSIR-Radiophysics	McCready, L.L., & Pawsey, J.L. & Payne-Scott, R.	1947	RSPSA 190, 357	(54)

Table 2. Cont.

#	Title	Affiliation	Author(s)	Year	Journal Vol. Page	Cites
13.	Microwave Thermal Radiation from the Moon	CSIR-Radiophysics	Piddington, J.H. & Minnett, H.C.	1949	AuSRA 2, 63	(49)

Table 3. The ten (plus 2) most cited articles from 1951 to 1955 are numbered in column 1. The 12 most cited articles shown here involve 14 distinct authors.

#	Title	Affiliation	Author(s)	Year	Journal Vol. Page	Cites
1.	The Luminosity Function and Stellar Evolution	MSO	Salpeter, E.E.	1955	ApJ 121, 161	(4645)
2.	Electrons Screening and Thermonuclear Reactions	MSO	Salpeter, E.E.	1954	AuJPh 7, 373	(369)
3.	On the Distribution of Mass and Luminosity in Elliptical Galaxies	MSO	de Vaucouleurs, G.	1953b	MNRAS 113, 134	(234)
4.	Electric Currents in the Ionosphere. I. The Conductivity	Amalgamated Wireless Ltd & Radio Research Board	Baker, W.G. & Martyn, D.F.	1953	RSPTA 246, 281	(208)
5.	A Survey of Southern HII regions	MSO	Gum, C.S.	1955	MmRAS 67, 155	(130)
6.	Evidence for a local supergalaxy	MSO	de Vaucouleurs, G.	1953a	AJ 58, 30	(106)
7.	Electric Currents in the Ionosphere. III. Ionization Drift due to Winds and Electric Fields	Radio Research Board	Martyn, D.F.	1953	RSPTA 246, 306	(102)
8.	Aerial Smoothing in Radio Astronomy	CSIRO-Radiophysics	Bracewell, R.N. & Roberts, J.A.	1954	AuJPh 7, 615	(92)
9.	Harmonics in the Spectra of Solar Radio Disturbances	CSIRO-Radiophysics	Wild, J.P. & Murray, J.D. & Rowe, W.C.	1954	AuJPh 7, 439	(88)
10.	The Theory of Magnetic Storms and Auroras	MSO	Martyn, D.F.	1951	Nature 167, 92	(80)
10.	The so-called Periastron effect in close eclipsing binaries	Riverview College Obs.	O'Connell, D.J.K.	1951	PRCO 2, 85	(80)

Table 3. Cont.

#	Title	Affiliation	Author(s)	Year	Journal Vol. page	Cites
10.	Red and Infrared Magnitudes for 138 Stars Observed as Photometric Standards	Lick Obs. (USA) & MSO	Kron, G.E. & White, H.S. & Gascoigne, S.C.B.	1953	ApJ 118, 502	(80)

Table 4. The ten most cited articles from 1956 to 1960 are numbered in column 1, and involve 17 distinct authors. Eleven distinct authors can be found above the horizontal line.

#	Title	Affiliation	Author(s)	Year	Journal Vol. Page	Cites
1.	A catalogue of H α -emission regions in the southern Milky Way	MSO	Rodgers, A.W. & Campbell, C.T. & Whiteoak, J.B.	1960	MNRAS 121, 103	(317)
2.	Radiation Transfer and the Possibility of Negative Absorption in Radio Astronomy	CSIRO-Radiophysics	Twiss, R.Q.	1958	AuJPh 11, 564	(197)
3.	Interferometry of Intensity Fluctuations in Light. I. Basic Theory...	Jodrell Bank (UK) & CSIRO-Radiophys.	Hanbury Brown, R. & Twiss, R.Q.	1957	RSPSA 242, 300	(170)
4.	Red and infrared magnitudes for 282 stars with known trigonometric parallaxes	Lick Obs. (USA) & MSO	Kron, G.E. & Gascoigne, S.C.B. & White, H.S.	1957	AJ 62, 205	(170)
5.	A Catalogue of Radio Sources between Declinations +10° and −20°	CSIRO-Radiophysics	Mills, B.Y., Slee, O.B. & Hill, E.R.	1958	AuJPh 11, 360	(143)
6.	A Catalogue of Radio Sources between Declinations −20° and −50°	CSIRO-Radiophysics	Mills, B.Y., Slee, O.B. & Hill, E.R.	1960	AuJPh 13, 676	(130)
7.	Geomagnetic Storm Theory	CSIRO-Radiophysics	Piddington, J.H.	1960	JGR 65, 93	(129)
8.	...Speed of the Solar Disturbances responsible for Type III Radio Bursts	CSIRO-Radiophysics & MSO	Wild, J.P., & Sheridan, K.V. & Neylan, A.A.	1959	AuJPh 12, 369	(120)
9.	Strip Integration in Radio Astronomy	CSIRO-Radiophysics	Bracewell, R.N.	1956	AuJPh 9, 198	(114)
10.	On the chemical evolution and densities of the planets	The ANU: Dept. of Geophysics	Ringwood, A.E.	1959	GeCoA 15, 257	(112)

Ronald Gordon Giovanelli (1915–1984: Piddington [84,85], Sheridan [86]) from Grafton, NSW, obtained his M.Sc. from the University of Sydney in 1939, 4 years before Stibbs. During the war, within the CSIR's National Standards Laboratory (which became the Division of Physics in 1945), Giovanelli developed many things. These included safety goggles to protect the eyes of anti-aircraft spotters/gunners while watching for dive-bombers attacking from the direction of the Sun, and aircraft illumination panels that do not spoil one's night-adapted vision. His most important astronomical research published in 1946–1947 was the notion of magnetic field reconnection for generating solar flares [87,88]. From 1958–1974 he was the Chief of the Division of Physics. His team built the solar optical observatory at Culgoora. In 1984 at the sixth National Congress of the Australian Institute of Physics, he was remembered through a series of Solar-Terrestrial Physics Workshops co-sponsored by the Australian Academy of Science, dedicated to his memory.

Clabon (Clay) Walter Allen (1904–1987: Stibbs [89], McNally [90]) from Subiaco, Perth, was one of the original 1926 staff employed by W.G. Duffield at the Commonwealth Solar Observatory. Clay had recently obtained his B.Sc. from the University of Western Australia. While observing the 1940 solar eclipse from South Africa, he obtained measurements (published after the war, in 1946–1947) of the electron density in the solar corona. These proved highly useful for radio astronomers [91,92]. Later on, working at the University College, London, and as Director of the University of London Observatory at Mill Hill from 1951–1973, he authored the highly useful "Astrophysical Quantities" ([93,94], cited over 1400 times). The third edition [95] has been cited over 4300 times and was published as Allen retired and returned to Mount Stromlo Observatory. Due to the multiple editions of his book³⁴, C.W. Allen is one of Australia's most well-known names in astronomical circles around the globe.

John Gatenby Bolton (1922–1993: Kellermann [97,98], Wild and Radhakrishnan [99]) was born in Sheffield, England, one year before J.P. Wild. While also in the Navy during World War II, Bolton visited Australia and later started work in the CSIR's Division of Radiophysics in 1946. From Dover Heights, he advanced the radio interferometer using the sea as a reflecting element (see [100]). He and his colleagues discovered three radio sources in the sky, matched these with optical counterparts, and thereby in their 1949 article they discovered (two) extragalactic "radio galaxies" [101]. From 1955–1961, Bolton also helped establish Caltech's "Owens Valley Radio Observatory" in the USA, before returning to CSIRO to oversee the construction of the Parkes radio telescope which subsequently identified the location of thousands of extragalactic radio sources and helped discover the extreme distances of quasars (see [102,103]). Arising from the "John G. Bolton Memorial Symposium", a special issue of the Australian Journal of Physics [104] is devoted to Bolton, and since 1998 he is additionally honoured through the "The Bolton Fellowship" administered by CSIRO Astronomy and Space Science.

Gordon James Stanley (1921–2001: Kellermann [42], Kellermann et al. [105]) came from Cambridge, New Zealand. From 1944 he helped build radio receivers in Australia before relocating to the USA at the start of 1954. He constructed the 200 MHz receiver for Allen's solar antenna located at the Commonwealth Solar Observatory. Working with Bolton at Caltech from 1954 to 1961, he found the site for, and from 1961 to 1975 was the first Director of, the Owens Valley Radio Observatory. While **Owen Bruce Slee** (1924–2011: Orchiston [106]) of Adelaide was the third key player in the exciting 1940s discovery of extra-galactic radio galaxies, he is also well known for his catalogs of radio sources produced a decade later. A detailed and worthy tribute to Slee, and his 60 years in radio astronomy, is given in a special issue of the Journal of Astronomical History and Heritage [107]. Today, AGN emissions from radio to tera-electron volt (TeV) energies offer exciting clues to understanding the these systems' emission processes (e.g., [108]).

³⁴ In honour of C.W. Allen's work, the 4th edition, although prepared and edited by Cox 2000, is called "Allen's Astrophysical Quantities" [96].

British-born **Richard van der Riet Woolley, Sir** (1906–1986: Davies [109], Feast [110], Lynden-Bell [111], McCrea [112], Stickland [113]) went to South Africa at age 15, obtaining his B.Sc. and M.Sc. (at age 19) from the University of Cape Town before returning to England to obtain his Ph.D. from the University of Cambridge. He was (i) the second Director³⁵ (referred to as the Commonwealth Astronomer at that time) of the Commonwealth Solar Observatory, later known as the Commonwealth Observatory by 1950, in Canberra (1939–1955), and (ii) the UK “Astronomer Royal” (1956–1971), and (iii) the Director of the South African Astronomical Observatory (1972–1976) where he retired. Although just 33 when he started at the Commonwealth Solar Observatory, he is recognised as having been wonderful in the role and successfully transformed it from a solar observatory to a stellar and extra-galactic observatory. Together with Walter Stibbs, Woolley co-authored the valuable textbook about radiative transfer called “The outer layers of a star” [114]. He also co-wrote a ‘top-ten’ article from 1945 to 1950 with C.W. Allen about emission lines from the Sun’s corona [115].

Furthermore, Woolley succeeded in having the 74-inch optical telescope built at Mount Stromlo. It was the equal largest telescope in the Southern Hemisphere for two decades, along with the matching telescope in South Africa from which it was copied. Woolley was also an early and crucial supporter of the 3.9 m Anglo Australian Telescope. The “Woolley building” at Mount Stromlo Observatory was opened in 1995. In addition, the University of Cambridge in the UK host “Woolley Conferences” and offer “Woolley Studentships” for students primarily resident in the Southern Hemisphere and preferably from South Africa.

Although we have now been briefly introduced to the authors of the first ten papers in Table 2, there are many notable individuals from this period immediately following the war. Therefore, the additional five authors from the following three most-cited papers are included in Table 2 and mentioned below.

Born in Vienna, **Stefan (Steve) Friedrich Smerd** (1916–1978: Wild [116]) became a world-leading solar physicist after emigrating to Britain in 1938 and obtaining his B.Sc. degree from the University of Liverpool in 1942. Like most of the early radio astronomers, he had previously been recruited (in Britain) to work on secret projects connected with radar development, which ultimately brought him to the CSIR in 1946. Known for his theoretical work on the ‘quiet’ Sun [117], which is his 1950 entry in Table 2, he worked with J.L. Pawsey and applied his ideas to practical problems and observational data from the Sun. By 1971 he succeeded Wild as the Director of the solar observatory at Culgoora, but sadly died in 1978 while undergoing heart surgery at the Royal Prince Alfred Hospital, Camperdown.

Joseph (Joe) Lade Pawsey (1908–1962: Bullard [118]) came from Ararat, Victoria, Australia, the birthplace of astronomer C.J. Merfield. Universities in Australia did not offer Ph.D. degrees until The University of Melbourne introduced them in 1944 [119]. Prior to this, Australian graduates would go to Britain for their research training. After Pawsey received his Ph.D. from Cambridge in 1935 (and after a few years with the Electric and Musical Industries Inc., EMI)³⁶, D.F. Martyn recruited Pawsey, who returned to Australia in 1940 to develop radar equipment at the CSIR radiophysics laboratory. After WWII had finished, as with others noted earlier, Pawsey and his group turned their antennae and attention to the Sun, finding enhanced radio emission associated with sunspots. Pawsey is sometimes referred to as the ‘Father of radio astronomy in Australia’. This is in part for having helped introduce radio interferometry (via the sea-reflection interferometry technique using the cliff-top aerial at Dover Heights), for his leading role in introducing the Fourier Synthesis concept [121]³⁷, and of course for his textbook “Radio Astronomy” [122]. Having been the Assistant Chief of the Division of Radiophysics from 1951, he passed away in 1962 just before taking up the Directorship of the US National Radio Astronomy

³⁵ From 1929–1939 the Commonwealth Solar Observatory was in the care of Mr W.B. Rimmer after the early death of W.G. Duffield.

³⁶ Sir Ernest Thomas Fisk (1886–1965: Given [120]) headed Amalgamated Wireless (Australasia) from 1917 to 1944, and was managing director of EMI in London from 1945 to 1951.

³⁷ The article by McCready, Pawsey & Payne-Scott (1947) was submitted with Pawsey as the lead-author. However, the journal’s editor made the order alphabetical (R.D. Ekers, priv. comm. 2015).

Observatory in Green Bank, West Virginia. Pawsey is remembered through the annual Pawsey Memorial Lecture and the “Pawsey Medal” which has been awarded since 1967 by the Australian Academy of Science (of which he was a founding Fellow) to recognize outstanding research in any field of physics by an Australian scientist under 40 years of age. The Pawsey crater on the Moon is named after him, as is the Pawsey Centre, and the Pawsey Supercomputing Centre in Perth—housing one of the most powerful petascale supercomputers in the Southern Hemisphere. It is used for, among other things, processing and storing data from CSIRO’s Australian SKA Pathfinder (ASKAP) Telescope.

During the 1910s, there must have been something in the water at Grafton, NSW, or perhaps a particularly inspiring local teacher. **Ruby Payne-Scott** (1912–1981) was also born in Grafton, just three years before R.G. Giovanelli. In 1941, Payne-Scott (after **Joan Jelly, née Freeman**³⁸, 1919–1998: Freeman [123]) was one of the first two female radio astronomers employed by CSIR in Australia. She worked at the Radiophysics Laboratory at the University of Sydney, where she had obtained a B.Sc., M.Sc., and Dip.Ed. over the previous decade, often as the only girl in the class—as was the case with Joan Freeman. Payne-Scott used the facilities at Dover Heights, Hornsby, and Potts Hill, and during the war she performed top-secret work investigating radar. In 1915, during WWI, women had to march through London for the right to join the war effort, but by WWII, women’s wartime services were recognised and encouraged (Figure 1). Payne-Scott helped monitor the positions of aircraft flying off Australia’s coast during WWII and is famously said to have protected Australia’s coastline with radars maintained with ‘coathangers and sticky tape’.



Figure 1. National Service Office poster from WWII featured on a 1991 Australian postage stamp commemorating the 50th Anniversary of Women’s Wartime Services.

Payne-Scott had a prominent role in the first radio astronomical interferometer observation in 1946 (of the rising Sun over the sea). She openly noted (see the references in [78]) that this research followed the war-time radar detection of the Sun by people such as **Dr Frances ‘Elizabeth’ Somerville Alexander, née Caldwell** (1908–1958: Sullivan [124], Orchiston [125]), who had a truly remarkable life and career³⁹). The Sun had also been observed at radio wavelengths by O.B. Slee at the RAAF Radar Station 59 in Darwin [107] and it was first detected in 1942 by Appleton and Hey [73] and independently by G.C. Southworth, who would later detect it at microwave (centimeter) wavelengths [126]. Payne-Scott went on to research Type I and III solar radio bursts and had astronomy publications from 1946 to 1952. Secretly married in 1944, it was kept a secret for six years because back then, and until 1966, married women could not hold a permanent position in the public

³⁸ Joan Freeman was exceptionally smart and seemingly came first in everything she did. She received numerous prizes while in Australia, including the Fairfax Prize. At the end of WWII (after having obtained a B.Sc. in 1939, and an M.Sc. in 1943, under Victor A. Bailey while she also worked for the CSIR), the CSIR offered her a Senior Studentship to attend Cambridge for her Ph.D. Her story from early hardship in Perth to international success is impressive. She became a world-leading Nuclear Physicist and, in 1976, was the first woman to receive the Rutherford Medal (shared with Roger Blin-Stoyle).

³⁹ Alexander was at the time operating radar for the Royal New Zealand Air Force and a former Captain in the British Royal Navy.

service. In 1950, she lost her permanent position before ‘resigning’ in 1951 when she had her first child⁴⁰ with PMG telephone mechanic William (Bill) Holman Hall (1911–1999: Goss and McGee [82]). Since 2008, she is remembered through CSIRO’s “Payne-Scott Award” to support researchers who have taken extended leave to care for a newborn child or family-related matters. Many articles and at least two books [82,127] have been written about her. With combinations of WWII intrigue and secrecy⁴¹, pioneer intellect, and discrimination from the authorities, the story of Payne-Scott, Freeman, Martyn, Piddington, Alexander, and others, is in some ways Australia’s version of the motion picture “The Imitation Game” involving Alan Mathison Turing (1912-1954: Hodges [128,129]), the WWII codebreaker and computer pioneer who features on the UK’s new 50 pound note.

Jack Hobart Piddington⁴² (1910–1997: Melrose and Minnett [130]) came from Wagga Wagga, NSW, 120-odd km south-east from the country town Leeton, where L.L. McCready came. Piddington was a highly-cited theoretical astrophysicist who worked on cosmic plasma physics and electrodynamics. However, Piddington was much more than that. As with Joan Freeman, he won an astounding number of prizes and awards while studying at school and then at the University of Sydney before obtaining his Ph.D. and yet more scholarships at Cambridge, England. Having aided the British Air Ministry and Royal Air Force while working at Cambridge⁴³, where Appleton⁴⁴ had been his Ph.D. supervisor and godfather to his son, he became a tremendous asset to Australia. During WWII, he was instrumental in the secret development of Australia’s shore-defence radar. He designed Sydney’s first aircraft-detecting (air-raid warning) system within five days of the bombing of Pearl Harbour by the Japanese (7 December 1941). These radars were constructed at the Radiophysics Labs and by the NSW Railways and “Her Majesty’s Voice” (HMV). While a set was rushed to Darwin at the end of January 1942, the RAAF was not able to get it operational before the devastating bombing of Darwin by the Japanese on 19 February 1942. One month later, Piddington was up there helping with the installation, which he achieved just in time to detect another secret Japanese raid which was then intercepted and thankfully dispersed by US fighters just 30 km out to sea. If not for Piddington, Darwin would have been bombed a second time, not to mention other cities in Australia that were spared WWII bombing raids thanks to the new radar detection [131,132].

Piddington does not have the recognition that one might expect. Moreover, according to Keith David Cole (1929–2010: Dyson and Cole [133]), who is quoted by Melrose and Minnett [130], Piddington’s somewhat withdrawn nature later in life meant that he did a lot of outstanding research in Australia but did not always receive fair credit. Raised by his mother since he was six, she can be proud of his contributions to Australia. Although Piddington and D.F. Martyn worked together, they could not publish their war-time work. Their 200 MHz Shore Defence (ShD) radar, which was later used by early radio astronomers, was installed at 17 sites around Australia’s coastline during WWII. Such was its success that Air Chief Marshal Sir Robert B. Popham requested Piddington to advise on suitable sites in Singapore⁴⁵ (where Dr ‘Elizabeth’ Alexander was stationed) and several other countries in Asia. After the war, and partly due to the subsequent dominance of observational research in Australia, as opposed to (Piddington’s post-1956 preference for) theoretical research, Piddington was the sole-author on almost all of his refereed publications⁴⁶, and he collaborated on just three papers from 1954 to 1985. Following Pawsey & Bracewell’s

⁴⁰ Her son, Peter Gavin Hall, went on to become one of Australia’s top mathematicians at The University of Melbourne.

⁴¹ A member of the Communist Party, as was Rachel Makinson’s husband Richard Makinson, the Australian Security Intelligence Organisation (ASIO) had a large file on Ruby Payne-Scott’s activities.

⁴² The middle name originates from his great-great-grandparents, who came to Australia and started their new life in Hobart around 1836.

⁴³ Piddington from Australia was friends at Cambridge with Ernest Rutherford (1871–1937) from New Zealand, who received the 1908 Nobel Prize in Chemistry.

⁴⁴ Sir Edward Victor Appleton (1892–1965) won the 1947 Nobel Prize in Physics for his research into the “Appleton layer” of the atmosphere and the ionosphere more generally, which involved his development of radar.

⁴⁵ Before Piddington’s radar could be installed in Singapore, on 8 December 1941 it was bombed, and on 15 February 1941 it fell to the might of the Japanese. This was arguably Britain’s worst defeat in WWII.

⁴⁶ Not included in ADS is Appleton and Piddington [134], regarding the ionosphere.

book “Radio Astronomy” [122], Piddington published his own valuable book in 1961 with the same title [135].

While briefly involved with *observational* astronomy from 1949 to 1956, Piddington co-authored five papers with engineer **Harry Clive Minnett** (1917–2003: Thomas and Robinson [136]) from Sydney. While almost everyone else at that time continued to perform metre wavelength observations of the Sun, Piddington and Minnett followed Southworth Southworth [126] and pushed into the microwave regime, where they successfully studied the Moon and correctly inferred properties of its dust layer [137]. In 1985–1986, Minnett was the Deputy Chief Executive of Interscan International Limited, a spinoff company of the Division of Radiophysics which started by developing a microwave approach and landing system for aircraft in the 1970s. Working with J.H. Piddington, he also discovered the powerful radio source Sagittarius A [138], now known to be powered by a 4 million solar mass black hole at the centre of our Galaxy. Not only a research astronomer but also an engineer, Minnett joined CSIR in 1940 as an assistant research officer and was to later successfully help lead the Parkes 64 m radio telescope to completion. He worked in the Parkes telescope control room during the Apollo 11 lunar landing, provided significant contributions to the construction of the 3.9 m Anglo-Australian Telescope [139], and eventually became Assistant Chief (1972–1978), and then Chief, of the Division of Radiophysics from 1978 until his retirement from CSIRO in 1981.

3.2. 1951–1955

With a remarkable 4645 citations (in 2014) and counting, the article by Austrian-born and Australian-educated **Edwin Ernest Salpeter** (1924–2008: Hoffman [140], Trimble and Terzian [141]) about “The Luminosity Function and Stellar Evolution” [142] is not just the most cited Australian astronomy article from 1951–1955 but is (within the ADS) the world’s most cited astronomy article from that period. In fact, as of writing, no pre-1970 astronomy article has more citations than this within the ADS. Salpeter wrote this work about the initial mass function of stars (recently reviewed by Hopkins [143]) while he was at Mount Stromlo Observatory, on leave of absence from Cornell University (USA). Belonging to a Jewish family in Austria, Salpeter had previously (in 1939) escaped to Australia as a teenager during WWII. After two years at Sydney Boys High School and obtaining a B.Sc. and M.Sc. from the University of Sydney, in 1945 he left for England to undertake his Ph.D. at Birmingham University before spending his career at Cornell University. While at Mount Stromlo in 1954–1955, he also published on refined nuclear reaction rates inside of stars, producing the second most-cited Australian article from 1951 to 1955 [144]. Salpeter maintained ties with Australia, and one of his very last articles, from the year he died, was in the Publications of the Astronomical Society of Australia and reviewed the state of Nuclear Astrophysics prior to 1957 [145].

G rard Henri de Vaucouleurs (1918–1995: Burbidge [146], Capaccioli and Longo [147], Buta [148]) from France joined the staff at Mount Stromlo Observatory in 1951 as their first Research Fellow. In 1953 he furthered his famous $R^{1/4}$ galaxy model [149] to describe the projected (on the plane of the sky) radial light profiles of early-type galaxies [150]. This model had a very successful run and was eventually replaced by the 1963 $R^{1/n}$ model of Jos  Luis S rsic [151,152]). In 1954, and published in de Vaucouleurs [153], G rard discovered a Local “supergalaxy”. This represented a supercluster of nearby galaxy clusters and bright galaxies orientated in a plane which runs roughly perpendicular to that of our Milky Way. He is also known for proposing a flat, rotating disk model for the Large Magellanic Cloud (LMC) [154], which was confirmed by Kerr, McGee and others at the Radiophysics Lab with 21-cm observations. Combining their ideas and results, Kerr and de Vaucouleurs [155] was the first extragalactic 21 cm astronomy article. de Vaucouleurs [154] also advocated that there had been a past interaction between the Milky Way and the LMC, a result later supported by Kerr’s observations of our galaxy’s disturbed gas disc [156]. After solidifying his mark on astronomy, de Vaucouleurs left Mount Stromlo in 1957. Among other things, he went on to announce at an International Astronomical Union (IAU) meeting in Canberra that the

Milky Way galaxy is barred [157]. He is, of course, also known for his *Reference catalogues of bright galaxies* (for example, [158]), compiled with his astronomer wife **Antoinette de Vaucouleurs, née Piétra** (1921–1987: Baize [159], Bottinelli et al. [160], Bash et al. [161]) and other key contributors. While at Mount Stromlo, Antoinette produced the first luminosity and spectral classification of 366 southern-hemisphere B, A, and F stars on the Morgan-Keenan system [162]. When Antoinette died, a special conference was held in her (and Gérard’s) honour [163,164].

It is interesting that de Vaucouleurs and Eggen [165]⁴⁷ reported variability in eta Carinae (Figure 2). Mr Francis Abbott (1799–1883: [169]) had claimed that the nebulae surrounding this star also varied [170,171]. However, his discovery from Tasmania was met with stern criticism in the 1860s by the British and European astronomical establishment [172,173]. Mr Abbott was an English watchmaker sent to Tasmania in 1845 as a convict.⁴⁸ While using a pair of binoculars from Mount Stromlo Observatory, de Vaucouleurs noticed that the star was brighter than reports from almost half a century earlier. As discussed in the scholarly review of η Carinae by de Vaucouleurs [174], it was D. O’Connell (Director of the Riverview College Observatory operated by the Saint Ignatius’ College, Riverview, Sydney) who subsequently discovered in a long series of patrol plates that eta Carinae had brightened by 1 mag more than a decade earlier in June 1941. Increasing from 8.5 to 7.5 mag, it was still much fainter than its peak in 1843, when it became the second brightest star in the sky after Sirius, and brighter than α Carinae—known as Canopus—the (usually) second brightest star in the sky.⁴⁹

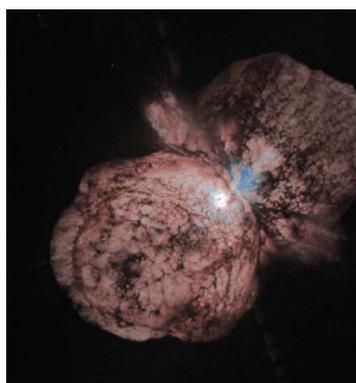


Figure 2. The star η Carinae. HST image credit: Jon Morse (University of Colorado), and NASA.

Dr W.G. Baker was not (primarily) an astronomer but rather was affiliated with the electronics manufacturer and broadcaster Amalgamated Wireless (Australasia) Ltd., where L.L. McCready had also worked. AWA Ltd. was Australia’s largest designer and builder of radios and televisions in the 1900s, and they still exist today as an ICT company. As the title of Baker’s 1953 paper [67] reveals, his work pertained to the conductivity of electric currents in the Earth’s ionosphere. Another highly-cited Australian paper, but not listed in the Tables because by the 1960s it starts to fall under the banner of atmospheric physics rather than astronomy, pertained to the “excitation of atmospheric oscillations”. It was written by Butler⁵⁰ & Small [178] while working at The Daily Telegraph Theoretical Department⁵¹ within the School of Physics at the University of Sydney. This unusual name

⁴⁷ **Olin Jeuck Eggen** (1919–1998: Eggen [166], Freeman et al. [167], Trimble et al. [168]), from the USA’s Lick Observatory, had an extended visit to Mount Stromlo Observatory in 1951, where he was later the Director from 1966 to 1977.

⁴⁸ We have not established if Abbott’s wife, Mary Woolley, was a relative of English-born Richard vdR. Woolley (1906–1986), the Director of the Commonwealth Observatory in Canberra from 1939 to 1955.

⁴⁹ The central star is expected to explode as a supernova any day now (astronomically speaking), hence explaining, in part, the large citation count to de Vaucouleurs and Eggen [165,175]. **Bart Jan Bok** (1906–1983: Gascoigne [176]), the third Director at Mount Stromlo Observatory, and his astronomer wife **Priscilla Fairfield Bok** (1896–1975), are well-known to have had a strong fascination and liking for the η Carinae nebula.

⁵⁰ Stuart Thomas Butler (1926–1982: Watson-Munro [177]).

⁵¹ The Daily Telegraph Theoretical Department was later named the Sir Frank Packer Theoretical Department.

for a Department came about because of the enabling donation by Sir Douglas ‘Frank’ Hewson Packer, media magnate, keen yachtsman, and patriarch of the Packer family. Packer ran The Daily Telegraph⁵², one of Australia’s leading newspapers, and he started the Australian Women’s Weekly (which would make for another interesting, and welcome, Departmental name).

Colin Stanley Gum (1924–1960: Bok [179]) was an undergraduate student from The University of Adelaide who worked with C.W. Allen at the Commonwealth Observatory. In 1946, they commenced the first 200 MHz radio map of the southern part of the Galaxy [180] using equipment built by G.J. Stanley and loaned by J.L. Pawsey from the Radiophysics laboratory. For Gum’s subsequent Ph.D. thesis undertaken at the Commonwealth Observatory, he used optical filters to discover 40 (new) ionised hydrogen clouds glowing red due to their $H\alpha$ emission. While such HII regions usually trace star formation (e.g., [181]), the giant “Gum Nebulae” [182] (see Figure 3) was later shown by radio astronomers to be ionised by the Vela supernova remnant. Combining his $H\alpha$ maps with those in the northern hemisphere [183] revealed the spiral structure of our Galaxy. Gum’s 1955 catalogue [184] was furthered by Rodgers et al. [185] at Mount Stromlo, and this is Australia’s most-cited article in the following 1956–1960 time interval (Table 4). While working with J.L. Pawsey, F.J. Kerr, and others, Gum also defined the new IAU System of Galactic Coordinates [186].

Possibly due to the stress of his Ph.D. (awarded in 1955), Gum suffered a nervous breakdown and his thesis was initially rejected. Tragically, Gum died aged just 36 in a skiing accident at Zermatt in Switzerland (28 April 1960). Employed by the University of Sydney in 1959, after three years with CSIRO’s Division of Radiophysics, he had been in Europe looking for a 36-inch telescope design to bring to Australia. However, the plan by Harry Messel at the School of Physics for a new optical observatory then had to be canned. The Gum crater on the Moon is named after Colin Gum.

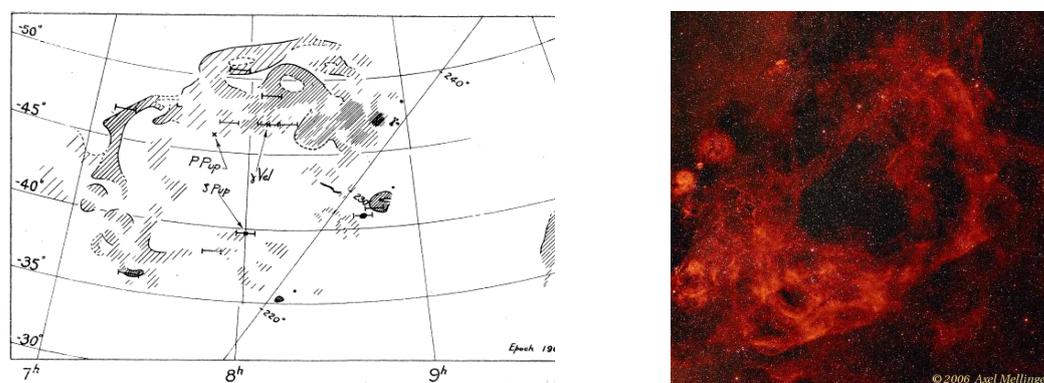


Figure 3. The Gum Nebula is not named after a similarly-shaped Australian gum leaf, but rather honours its discoverer Colin S. Gum. Some see a love heart while others see a face in this image. Left panel: Sketch from Gum’s 1952 paper. Right panel: $H\alpha$ image taken by Prof. Axel Mellinger, in 2006, with both the horizontal and vertical axis flipped.

Sydney-born **Ronald Newbold Bracewell** (1921–2007: Frater et al. [71], Petrosian [187], Thompson and Frater [188]) had the same traditional ‘educational trifecta’ as many of the astronomers listed here. He went to Sydney Boys High School, then the University of Sydney, and then Cambridge, England, for his doctorate. He was a major contributor to not just radio interferometry but also medical scanning. His signal processing techniques and mathematical methods of image analysis are now applied to medical images and X-ray tomography. During WWII, and while pursuing his engineering degrees from the University of Sydney, Bracewell also worked for J.L. Pawsey and H.C. Minnett by helping to develop radar at microwave wavelengths for the Royal Australian Navy before then spending 1946–1949 at Cambridge obtaining his Ph.D. in ionospheric research. Bracewell’s “strip

⁵² The Daily Telegraph was sold to Rupert Murdoch in 1972.

integration" article [189] (Table 4) explains how Fourier Transforms [190] can be used to create a two-dimensional image from a series of one-dimensional scans taken with different positional angles; a technique later adapted to (medical⁵³) tomography. His 1954 "aerial smoothing" article [195] (Table 3) also explained, using Fourier Transforms, how to restore the true profile of a source from an antenna scan, and, importantly, what information was lost and could not be recovered. He was an exceptionally inventive, capable, and active scientist who was lauded with many prizes and medals during his career. In 1998 he was named an officer of the Order of Australia, in recognition of his contributions to radio astronomy and image reconstruction.

Bracewell's successful 1955 book with Pawsey (titled "Radio Astronomy") undoubtedly contributed to his delivery of lecture courses in the USA at that time, and he subsequently became a Faculty member at Stanford University's Electrical Engineering department in 1955 until he retired from teaching in 1991. In 1965, albeit now at Stanford, he wrote a book called "The Fourier Transform and its Applications" [196], which has become a standard reference work, with updated editions published in 1986 and again in 2000. During the lunar missions and the first landing on the Moon, Bracewell's USA-based 32-dish solar spectroheliograph, which he built upon arriving in Stanford, was used by NASA to keep a daily look-out for dangerous solar outbursts. Given the onset of the space-race, and Bracewell's observations of Sputnik 1, Bracewell [197] famously speculated that alien probes might have been sent into the habitable zones of around a thousand stars nearby the alien civilisation's home star—to establish radio communications with other civilisations. Bracewell confidently wrote, over half a century ago, that "Our impending contact cannot be expected to be the first of its kind; rather it will be our induction into the chain of superior communities". He publicised his ideas further in his 1975 monograph titled "The Galactic Club: Intelligent life in outer space" [198]. His hypothesised messengers have become known as "Bracewell Probes".

After obtaining a Ph.D. under Fred Hoyle at Cambridge, **James (Jim) Alfred Roberts** (1927–: Roberts [199]) worked in the Division of Radiophysics from 1952 to 1958. During that time he co-wrote the important "aerial smoothing" paper [195] with R.N. Bracewell and characterised solar bursts of spectral Type II as observed from Dapto [200] from 1949 to 1957 [201]. Among other things, he noted that half of the bursts contained harmonic structure, that they could be observed from near the solar limb and not just the solar centre (with scattering and refraction implications), and that geomagnetic activity occurred two days later and thus implied particle travel speeds of 1000 km s^{-1} . He then spent some years at Caltech, Owens Valley, Arecibo, and as a visiting Professor at the University of Toronto before returning to Parkes where he continued to make significant contributions.

With an engineering degree from the University of Tasmania, **John D. Murray** joined CSIR in 1948 and remained a scientific staff member until 1989. After assisting with the Penrith radio-spectrograph in the late 1940s [202], he helped technical assistant **William (Bill) C. Rowe** (deceased 1954) build both the 40–240 MHz receivers and display for the Dapto radio-spectrograph, and then shared the observing with W.C. Rowe and J.P. Wild. Together they observed a Type II burst with a (first and second) harmonic structure [203]. A corner of the West Pennant Hills' orchard belonging to John Murray's father, known as *Rosebank*, was later to become the *Murraybank* Field Station [204] after increasing radio noise levels at Potts Hill [205,206] required them to move their receivers further out of Sydney [207].

⁵³ Bracewell is not the only astronomer from this era to have links with the medical profession. With an M.D. from Cornell University in 1925, and a Ph.D. from Princeton University in 1927, US-born Theodore (Ted) Dunham Jr (1897–1984: Notes [191]) co-discovered, through the use of optical spectroscopy, that the atmosphere of Venus contains large quantities of pressurised CO₂ and is thus not like Earth's atmosphere — ending decades of speculation [192]). Physicist and physician, from 1946 to 1957 he studied the spectrophotometry of cells in medicine and surgery at Harvard University and the University of Rochester, before joining Mount Stromlo Observatory in 1957, where he helped Ted Dunham Junior develop the coude spectrograph for their new 74-inch telescope [193]. Dunham then used this to study the spectrum of η Carinae [194] and other stars, and from 1965 to 1970 he worked at The University of Tasmania.

Father Daniel Joseph Kelly O’Connell, S.J.⁵⁴ (1896–1982: Bruck [208]) was born in England, studied in Ireland and the USA, and was the Director of the Jesuit Riverview College Observatory in Sydney from 1938 to 1952, before becoming the Director at the Vatican Observatory for the next 18 years. He specialised in variable stars, and his 1951 article [209] revealed that the difference in brightness between the maxima, on either side of the principal minimum, in eclipsing binary stars is *not* a ‘periastron effect’ as was previously thought. His monitoring of the sky from Sydney led to discovering the 1941 brightening of η Carinae. Father O’Connell is responsible for the large telescopes in the Barberini Gardens at Castel Gandolfo, upgrading from the smaller telescopes on the Papal Palace’s roof.

The three authors of the final article in Table 3 are familiar names, and they appear again in Table 4. We are introduced to them in the following subsection.

3.3. 1956–1960

Following the 1955 catalogue of Gum [184], the paper by Rodgers et al. [185] became the standard “RCW” reference for (182) southern HII regions. This paper had a significant impact in cementing Australia’s reputation as a significant player in astronomy. **Alexander (Alex) William Rodgers** (1932–1997: Freeman [210,211]) from Newcastle, NSW, passed away just weeks before his planned retirement from Mount Stromlo Observatory where he had presided as Director from 1986 to 1992. Among other works, Rodgers is also known for his spectrophotometry of η Carinae [212]. After obtaining an undergraduate degree from the University of Sydney, Rodgers started at Mount Stromlo as a Ph.D. student of Woolley’s in 1954, and he graduated in 1958. After a short stint at the Carnegie Observatories in Pasadena, and at the Royal Greenwich Observatory in the UK with R. Woolley, from 1959 onwards, Rodgers spent his career at Mount Stromlo. **Colin T. Campbell** was one of Bart Bok’s first Ph.D. students, although, after two years, Campbell decided to leave. **John Bartlett Whiteoak**⁵⁵ (1937–) was also an early student of Bok’s, graduating in 1962. After a stint at Caltech, where he first co-authored with V. Radhakrishnan (see later), Whiteoak joined the Division of Radiophysics in 1965 and was the Deputy Director of the ATNF from 1989 until retirement in 2001. In addition to his scientific discoveries, particularly his work on radio polarisation (for example, [214]), he is known for successfully campaigning for greater protection of the high-frequency (71–275 GHz) radio bands for astronomical observations.

Born in India and educated in England, **Richard Quentin Twiss** (1920–2005: Tango [215]) is known for the “Hanbury Brown and Twiss effect” [216,217], which led to the creation of the optical intensity interferometer.⁵⁶ They built the first in the UK in 1954. Despite much early skepticism from the scientific community as to its feasibility, it was famously used to measure (the optical size of the star) Sirius A [216]. Mathematician and electronics engineer Twiss later helped to construct the Narrabri Stellar Intensity Interferometer [219], which came online in 1965. Twiss is also highly cited for his paper [220] about coherent electron cyclotron maser emission, seen in, for example, Jupiter’s decimetric radio emission. Like Twiss, **Robert Hanbury Brown** (1916–2002: Hanbury Brown [221], Davis and Lovell [222]) was born in India and grew up in England, but unlike the very English Twiss, Hanbury Brown reportedly loved Australia. He was a physicist and astronomer who helped develop radar and establish radio astronomy in the UK. After constructing the (Hanbury Brown)—Twiss intensity interferometer in the UK, he came to Australia in 1962 (where he stayed for 27 years). He co-built and used the Narrabri Stellar Intensity Interferometer to measure the diameters of stars [223,224], enabling the calibration of the temperatures of stars hotter than the Sun. In 1975 he began work on the Sydney University Stellar Interferometer (SUSI), which came online shortly after he retired in 1981. In 1986 he received the Companion of the Order of Australia honour before returning to England in 1989.

⁵⁴ S.J. = Society of Jesus

⁵⁵ John Bartlett Whiteoak should not be confused with Jonathan Bartlett Z. Whiteoak, who obtained his Ph.D. from the University of Sydney in 1994 and published the ‘MOST supernova remnant catalogue’ (MSC: [213]).

⁵⁶ The technique was previously established and used at radio wavelengths to measure the structure of radio sources at very high spatial resolution [218].

Sidney Charles Bartholemew (Ben) Gascoigne (1915–2010: Watson [225]) from Napier, New Zealand, came to Canberra in 1941 after undertaking a Ph.D. in England. He was the first Vice-President of the Astronomical Society of Australia [226], and he remained at Mount Stromlo Observatory until his retirement in 1980. Initially, he worked on the design of gun-sights along with Walter Stibbs at the CSO. His 1952 paper with **G.E. Kron**⁵⁷ (1912–2012) reported the discovery of young “populous clusters⁵⁸” in the Magellanic Clouds, revealing that the Clouds had not strictly evolved in parallel with the Milky Way. They also found blue cepheid variables in the Small Magellanic Cloud, which led to a doubling of its distance from us, which confirmed a doubling of the Universe’s ‘distance scale’ [227,228]. Together with the US-colleagues **H.S. White** and **G.E. Kron**—who had brought over a photoelectric device from the Lick Observatory (USA) in 1953—they measured the first near-infrared magnitudes of stars in the Southern Hemisphere [229,230]. “Gascoigne’s leap” at the AAT remembers the site where Gascoigne (former joint Project Scientist, then senior commissioning astronomer, for the AAT) fell some six meters in 1974 from the interior walkway to the observation floor, breaking his arm.⁵⁹

Using the Mills cross radio telescope, from 1958 to 1961, Mills, Slee & Hill (MSH) published several catalogues [231–233] of radio sources at 3.5 m wavelengths (and they also mapped the Galactic plane at this wavelength Hill et al. [234]). In their useful catalogs, they reported 1159, 892, and 219 radio sources within declinations of +10 to −20, −20 to −50, and −50 to −80 degrees. Like so many other astronomers mentioned here, **Bernard (Bernie) Yarnton Mills** (1920–2011: Frater et al. [71], Bhathal [235], Frater et al. [236]) from Manly obtained his undergraduate degree from the University of Sydney. Equipped with this, in 1942, he started to help develop radar receivers and displays under Joe Pawsey at CSIR, and he went on to obtain his Masters of Engineering in 1950 and Doctor of Science in Engineering in 1959. He is known for designing and building the 450 m long “Mills Cross telescope” [237] that was at Fleurs—now called Badgery’s Creek where Sydney’s second airport is under construction—in which the fan beams of two long antennae at right-angles to each other were combined to produce a (49 arcmin) pencil beam [238]. Left without adequate CSIRO funding—which was committed to the Parkes radio telescope and the Culgoora Radioheliograph—in 1960, he and Wilbur Norman “Chris” Christiansen (1913–2007: Frater and Goss [239], Orchiston and Mathewson [240]) of the “Chris Cross Telescope” left CSIRO and joined the staff at the University of Sydney. In 1967 they completed the “Super Cross” (aka One-Mile Mills Cross) telescope with 1.6 km arms out near Bungendore, 30 kilometres east of Canberra. In 1978 this telescope’s north–south arm was removed, and the east–west arm reconfigured to give us the Molonglo Observatory Synthesis Telescope (MOST), which operates today, albeit with various upgrades [241,242]. The Molonglo Reference Catalogue [243] identified 12,000 radio sources, a five-fold increase on the MSH survey. As we have already encountered O.B. Slee in Section 3.1, we quickly note here that **Eric R. Hill** obtained his physics degree from the University of Melbourne in 1951. He then joined the CSIRO group in Sydney. From 1957 to 1971, he published some 20 articles after a traineeship at the Leiden Observatory (1953–1956), which resulted in his derivation of our Galaxy’s gravitational field perpendicular to the plane [244].

We have now met the first eleven authors from Table 4, and having already met Piddington, Wild, and Bracewell, this leaves Sheridan, Neylan, and Ringwood.

In 1959 Wild, Sheridan & Neylan revealed that the coronal plasma oscillations responsible for Type III radio bursts were excited by flares moving at half the speed of light, and faster [245]. These flares launched protons and electrons up into, and out of, the corona, with some of the electrons trapped by the corona’s magnetic field lines subsequently emitting ‘Type IV’ synchrotron continuum radiation. **Kevin V. Sheridan** (1918–2010) was born in Brisbane. He joined CSIR in 1945, working on the Mills Cross radio telescope, and later

⁵⁷ Kron was a (highly successful) American-astronomer, on an extended visit to Mount Stromlo Observatory in 1951, and was later a Senior Research Fellow at Mount Stromlo from 1974 to 1976.

⁵⁸ In terms of star formation and luminosity, “populous clusters” reside between open star clusters and super star clusters.

⁵⁹ In the early 1990s, Dr Brett Wells also fell and injured himself badly from within the darkness of the AAT dome.

engaged in radio astronomy research in 1953 after obtaining his B.Sc. degree from the University of Queensland. At Dapto, he was the chief electronics engineer and widely acknowledged by J.P. Wild as the “man who put it all together”. Sheridan later became the solar group leader at Culgoora from 1975 until retiring in 1984. As a Mount Stromlo Ph.D. student, **Tony Neylan** spent much of 1958 at Dapto, thanks to a CSIRO Research Grant, helping with the observations and analysis of the radio-interferometer data concerning the coronal heights of Type III solar radio bursts and the associated Type IV emission. He later dropped out of the Ph.D. program to join the Diplomatic Service [246], and apparently [200] after that became a Jesuit Priest like Father O’Connell.

Alfred Edward (Ted) Ringwood (1930–1993: Green [247], Wanke [248], Irifune and Kesson [249]) was born in Kew, Victoria, just up the road from what was then the Swinburne Technical College. He obtained his Ph.D. in Geology from Melbourne University in 1956. He was a geochemist and geophysicist who spent most of his career at The ANU’s Department of Geophysics, which in 1964 became the Department of Geophysics and Geochemistry while still under the Directorship of J.C. Jaeger, and then became the Research School of Earth Sciences in 1973 (with Ringwood the Director from 1978 to 1983). Ringwood has an impressive list of honours and awards [250], and it is not surprising that his (self-explanatory titled) works appear in not just the table for 1956–1960, but also for 1961–1965 and then again for 1966–1969. In addition to his 1959 article about the chemical evolution and densities of the planets [251], his 1961 article about the chemistry of meteorites [252], and his 1966 article about the chemistry of the planets [253], Ringwood has two other equally well-cited articles from the 1960s which we have not included because, pertaining to the Earth’s mantle, they are more of a geological than astronomical nature. Ringwood’s substantial international recognition helped our nation’s reputation as a key contributor in the field of high pressure petrology, geochemistry, planetary and meteoric mineralogy. His analysis of Moon rocks returned from the Apollo missions led to his recognition of their similarity with Earth and the idea that the Moon was in some way derived from the Earth’s mantle [254,255]. The mineral “ringwoodite”, discovered in fragments of the Tenham meteorite, contains a specific structure previously predicted to exist by Ringwood and, as such, now reflects his name. Since 2012, Ted Ringwood is additionally honoured through the Ringwood Medal, administered by the Geological Society of Australia.

3.4. 1961–1965

From 1956 to 1961, Japanese **Tetsuo Hamada** was a postdoctoral fellow at the University of Sydney’s School of Physics, where he authored the important paper with (the then visiting) astronomer E.E. Salpeter, introducing the “Hamada–Salpeter White Dwarf Model” [256]. Little more than a decade after WWII had ended with the dropping of nuclear bombs on Japan, Hamada’s appointment to work on matters related to nuclear reactions revealed how science can often transcend politics. Properly allowing for inverse β decays at high densities, where electrons tunnel into nuclei and create neutrons, Hamada and Salpeter developed an improved mass-radius relation for white dwarf stars: dead stars supported by the degeneracy pressure of the free electrons. Salpeter further explored what happens once the thermal energy in a plasma/star is zero [257]. Working in the Daily Telegraph Theoretical Department, Hamada was as much a nuclear physicist (studying the interior of neutron stars and white dwarfs) as an astronomer. He is widely known for the “Hamada–Johnston potential model”. This analytical expression for an energy-independent nucleon-nucleon potential [258] was developed using Australia’s second electronic computer⁶⁰, with vacuum tubes that apparently filled a room, at a time when Japan had no electronic computers. This latter Australian-based paper [258] has been cited 900 times. In 1962 Hamada relocated to Ibaraki University, Mito, Japan, where he eventually became University President from 1988 to 1992.

⁶⁰ Following CSIRAC [259], SILLIAC was officially opened in 1956 by Adolph Basser who had previously donated 50,000 pounds (the prize money of his 1951 Melbourne Cup winner, Delta) for its construction, and then another 50,000 pounds in 1956 for its upgrade.

Table 5. The ten (plus 1) most cited articles from 1961 to 1965 are numbered in column 1, and involve 19 distinct authors. Ten distinct authors can be found above the horizontal line.

#	Title	Affiliation	Author(s)	Year	Journal Vol. Page	Cites
1.	Models for zero-temperature stars	Sydney Univ., Cornell Univ. & Cambridge (UK)	Hamada, T. & Salpeter, E.E.	1961	ApJ 134, 683	(595)
2.	Solar Bursts	CSIRO-Radiophysics	Wild, J.P., Smerd, S.F. & Weiss, A.A.	1963	ARA&A 1, 291	(382)
3.	Energy and Pressure of a Zero- Temperature Plasma	Cornell Univ., Sydney Univ. & Cambridge (UK)	Salpeter, E.E.	1961	ApJ 134, 669	(327)
4.	Variation of Radio Star and Satellite Scintillations with zenith angle	Univ. of Adelaide: Dept. of Physics	Briggs, B.H. & Parkin, I.A.	1963	JATP 25, 339	(172)
5.	Investigation of the Radio Source 3C 273 by the Method of Lunar Occultations	Univ. of Sydney & CSIRO-Radiophysics	Hazard, C. & Mackey, M.B. & Shimmins, A.J.	1963	Nature 197, 1037	(136)
6.	A study of the decimetric emission and polarization of Centaurus A	CSIRO-Radiophysics & Mount Stromlo	Cooper, B.F.C. Price, R.M., Cole, D.J.	1965	AuJPh 18, 589	(118)
6.	The Parkes catalogue of radio sources, declination zone -20° to -60°	CSIRO-Radiophysics	Bolton, J., Gardner, F. & Mackey, M.B..	1964	AuJPh 17, 340	(118)
7.	Galactic Velocity Models and the interpretation of 21-cm surveys	CSIRO-Radiophysics	Kerr, F.J.	1962	MNRAS 123, 327	(110)
8.	Population I in the Large Magellanic cloud	MSO & Uppsala Southern Station	Westerlund, B.	1961a	UppAn 5, 1	(100)
9.	Observations of Jupiter's radio spectrum and polarization in the range from 6 cm to 100 cm	CSIRO-Radiophysics	Roberts, J.A. & Komesaroff, M.M.	1965	Icarus 4(2), 127	(96)
10.	Chemical and genetic relationships among meteorites	The ANU: Dept. of Geophysics	Ringwood, A.E.	1961	GeCoA 24, 159	(87)

Having transferred from The University of Adelaide, where he had made radar observations of meteors and published about our ionosphere since 1953, Captain⁶¹ **Alan Austin Weiss** (1917–1964), born in Monreith, South Australia, came to Sydney around 1960 to supervise the analysis of the Dapto solar data. He wrote papers regarding Type II, III, and IV radio bursts, and working with J.P. Wild and S.F. Smerd, in 1963, he co-authored a detailed review article about the properties of solar bursts [260] before he died from leukaemia, as had W.C. Rowe roughly a decade earlier at Dapto. His work built on the 1942 discovery of radio bursts from sunspots made during WWII when such radar findings had to be kept secret [e.g., [72], and references therein].

British-born **Basil Hugh Briggs** (1923–1994: Elford and Vincent [261]) obtained his Ph.D. from Cambridge in 1952 and worked with the Cavendish Laboratory’s Radio Research Group from 1946 to 1961. While there, he explored the fading of radio waves reflected from an irregular ionosphere and developed a formula to determine the horizontal motion of the lower ionosphere using radar reflections measured by separated ground-based antennas [262]. In 1962 he joined The University of Adelaide, where he published papers for the next three decades, including work on the scatter and scintillation of radio waves due to irregularities in the ionosphere [263]. In the early 60s, Briggs faced the same problem as B.Y. Mills (who built the Molonglo telescope). CSIRO was committed to building two radio facilities (Parkes and the Culgoora Radioheliograph) and could not support others. However, The University of Adelaide was able to fund the construction of the Buckland Park Array, a 1×1 square kilometre array of 89 crossed dipoles that became the world’s largest low-frequency radio telescope. Rather than studying the heavens, it provided, and provides, detailed observations of the lower ionosphere. In 1968, co-author **I.A. Parkin** published a second paper on radio scintillation through the ionosphere before apparently leaving the University of Adelaide to join the Radio and Space Research Station of the Science Research Council in the UK. As his papers’ titles reveal, his work had implications for satellite communications (military defense, navigational, and civilian purposes).

Using the Parkes telescope and the Moon as a screen, in 1963, **Hazard, Mackey & Shimmins** reported [264] an accurate position for the ‘radio star’ 3C 273. This method was not the first time something like this had been done. For example, Hazard [265] had previously reported the position of 3C 212 to an accuracy of $3''$, and [266] had already taken optical spectra of other 3C ‘radio stars’ whose optical counterpart had been identified.⁶² However, Hazard et al. [264] were fortunate in that Maarten Schmidt became involved with 3C 273. In an adjoining Nature article, Schmidt [267] reported on his realisation that his optical spectra associated with the star-like object 3C 273 had a cosmologically-significant redshift of 0.158, that is, 3C 273 was receding at $1/6$ th the speed of light. The first quasar⁶³ had been identified, the steady-state model of the Universe was dead, and our known size of the Universe had dramatically increased.

Furthermore, the path to the discovery of supermassive black holes⁶⁴ had begun [271–273]. In 1963, the spectra of the previously studied ‘radio stars’ were also realised to be highly redshifted, and much later work continued to push this frontier (for example, [274]). While more than half a century on, the Hazard et al. [264] Nature article is still badged as a wholly CSIRO Division of Radiophysics publication. However, Hazard was actually employed by the University of Sydney in the Chatterton Astronomy Department within the School of Physics. The Department had recently been opened in 1961 to commission and operate the Narrabri Stellar Intensity Interferometer. Allegedly [275], an editorial blunder had affiliated Hazard with CSIRO rather than with the University of Sydney. However, it has since been noted that CSIRO changed the details of Hazard’s affiliation [272].

⁶¹ During WWII, Captain Weiss was enlisted on 17 November 1942.

⁶² A.R. Sandage did not believe that these objects were galaxies, but instead stars, because their brightness varied on short time scales.

⁶³ The term ‘quasar’ appears to have been introduced in 1964 by Chiu [268] to refer to “quasi-stellar radio sources”. The term QSO was later introduced to refer to optically-identified ‘quasi-stellar objects’ that were not detected at radio wavelengths.

⁶⁴ Kellermann [269] and Graham [270] extensively review the historical development of how we came to believe in black holes.

British radio astronomer **Cyril Hazard** obtained his Ph.D. at Jodrell Bank, where he mastered the timing of radio sources disappearing behind the Moon, and then reappearing, as a means to measure their position to arcsecond accuracy. He moved to the University of Sydney in 1961 to supervise the construction of the Hanbury Brown-Twiss Stellar Interferometer at Narrabri. Nowadays, Prof. Cyril Hazard has a long-term visitor status at the University of Cambridge. For his 3C 273 observation, the Parkes engineer and young physicist **M. Brian Mackey** set up the observing system. More than that, Mackey performed much of the data reduction and accounted for the Moon's rough, irregular circumference. He left radio astronomy a few years later, and little information could be found on him. **Albert John Shimmins** (1921–2007), the then deputy director of Parkes in 1963, was responsible for the telescope's wonderful pointing accuracy, and according to Miller Goss⁶⁵, it was J.G. Bolton who politely suggested to Hazard that Shimmins be included on the article rather than Bolton himself. Previously, from 1953 to 1961, Melbourne-born Shimmins had been employed by the organisation that became the Weapons Research Establishment at Salisbury and Woomera, where he worked on the electronic guidance for the Blue Streak intercontinental missile and rocket tracking systems. In 1961 he moved to CSIRO's radiophysics division at Parkes and installed their tracking computer and data recorder/processor. He was in the control room during the Apollo 11 lunar broadcast, and he led and co-authored many valuable radio source catalogs.⁶⁶ Upon retiring in 1981, after having served as the Officer-in-Charge at Parkes from 1971 to 1981, the University of Melbourne bestowed on them a Doctor of Science degree. He passed away⁶⁷ in East Malvern, Melbourne, in 2007. 'John' Shimmins is honoured through 'The Albert Shimmins Fund' that he very generously established (by donating over \$14.5M) at Melbourne University, from where he had obtained a Masters degree in electrical engineering in 1952. The fund supports scholarships and research activities in the Faculty of Science.

During a visit to Parkes⁶⁸, R.N. Bracewell (then at Stanford) discovered that the 10 cm wavelength emission from Centaurus-A was linearly polarised [277,278], just as it was at 3-cm [279]. The day after Bracewell left the Telescope, an enthusiastic R.M. Price repeated the observations using the 21 cm receiver, resulting in his first publication [280–282] coming out in *Nature* before Bracewell's article appeared. Subsequent mapping of the polarisation at three different positions, and more importantly, at different wavelengths, further revealed Faraday rotation from uniform large-scale magnetic fields in either our Galaxy or Centaurus-A⁶⁹ [286–289].

Brian F.C. Cooper (1917–1999) obtained his B.Sc. and B.Eng. (Electrical) from the University of Sydney in 1939 and 1941, after which he joined the CSIR Radiophysics wartime effort to develop radar. Helping J.H. Piddington, he played a major role introducing radar at Darwin after the Japanese air raid in early 1942. He later played a key role in helping to pioneer the manufacture of transistors in Australia [290] before developing receivers and correlators for the Parkes radio telescope [291]. Cooper became the Head of the CSIRO Division of Radiophysics' receiver group and has been described as something of an unsung hero in the development of Australian radio astronomy and transistors.

US-born **Richard Marcus Price** arrived at the Radiophysics Division in 1961 as a Fullbright Scholar with a B.Sc. degree and graduated with a radio-based Ph.D. from The ANU in 1966 under the supervision of Bart Bok (Mount Stromlo) and J.G. Bolton (Parkes). By 1969 Price had returned to the USA, working at the Massachusetts Institute of

⁶⁵ <ftp://ftp.aoc.nrao.edu/staff/mgoss/schmidt.cohen.4july09.txt> (accessed 15 February 2015).

⁶⁶ These included works with Beverley June Harris (later Wills) who obtained her Ph.D. from The ANU in 1969, Margaret E. Clarke, Ronald (Ron) David Ekers, Richard ('Dick') Norman Manchester, and others.

⁶⁷ To quote from the considerable obituary in *The Age* newspaper (29/11/2007), written by Dr Robert Shanks, "... to observe him [Albert J. Shimmins] walking to the shops in Albert Park or Windsor in his later life—an elderly man with a walking stick and cap, careless of dress, carrying a bag with his few needs—conjured the visage of an eccentric. However, Shimmins was far more. He was a distinguished scholar and scientist.

⁶⁸ Permission to observe was approved by Radiophysics Chief Bowen (1911–1991: Hanbury Brown et al. [276]), but this was apparently unbeknown to the Parkes Director Bolton.

⁶⁹ A historical article on Centaurus-A can be found in Robertson et al. [283], with more recent results in Davids et al. [284], and future studies of cosmic magnetism reviewed in Heald et al. [285].

Technology before becoming the Head of the Astronomy Department at the Albuquerque's University of New Mexico, where he worked from 1979 and is currently an emeritus professor. During this time, he did, however, return to Australia and was the Officer-in-Charge at the Parkes Observatory from 1994 to 1999.

The 1965 article with Cooper and Price appears to be the first from Engineer **Douglas (Doug) J. Cole** (deceased), who continued to publish under the CSIRO affiliation until at least 1978. In 1965, Cole used the Parkes radio telescope to track the position and Doppler shift of NASA's Mariner IV mission to Mars. Added to NASA's data, this collectively provided the first close-up images of Mars, which proved not to be the welcoming place that many had expected from earlier ground-based observations. For example, the drawings from Australia by Walter Frederick Gale (1865–1945: Wood [292]) in 1892 suggested a land of oases.⁷⁰ The pursuit of water on Mars continues to this day [293].

Francis (Frank) Fredrick Gardner (1924–2002: Milne and Whiteoak [294]) was another bright spark from Sydney who graduated in 1946 from the University of Sydney and then went to Cambridge University in the UK, where he obtained his Ph.D. in 1953. He had already started working at CSIRO's Division of Radiophysics in 1950, where he retired in 1988. He was a receiver engineer who also became a radio astronomer through the development of the Parkes radio telescope and specialising in polarisation studies [214] and astro-chemistry (molecules in space). The paper by Bolton et al. [295] titled "The Parkes catalogue of radio sources, declination zone -20° to -60° " served as a reference for the paper by Bolton et al. [296] titled "Identification of extragalactic radio sources between declinations -20° and -44° ", which just missed out on entering into Table 5. Both Ronald D. Ekers (on the preceding paper with Margaret E. Clarke⁷¹) and Jennifer A. Ekers⁷² (married to R.D. Ekers) contributed to these ongoing radio survey papers [297,298].

Frank John Kerr (1918–2000: Westerhout [299]) was born in St Albans, England, to Australian parents who returned to Australia after World War I had finished. He obtained his physics degree from the University of Melbourne, and if J.L. Pawsey is the father of radio astronomy in Australia, then Kerr is the father of 21 cm astronomy. He established the Southern Hemisphere 21-cm line program in the late 1940s and made sure that the surface of the Parkes radio telescope was built smoothly enough that observations down to 10-cm wavelengths could be performed [8]. Well before Parkes came online, Kerr made the first detection of a radio spectral line in an external galaxy, namely HI in the Magellanic Clouds. He also worked with Gérard de Vaucouleurs (who was at the Commonwealth Observatory) and others to determine the rotation and masses of the Magellanic Clouds [155]. Kerr additionally mapped the Milky Way at 21-cm [300] and coined the term "Galactic Warp" in 1956 to describe the gravitational effect of the Magellanic Clouds on our Galaxy [156]. Having helped to precisely determine the plane of the hydrogen gas in our Galaxy, his work became the basis of our new galactic coordinate system [301], while his other work strengthened the view that the Milky Way is a spiral galaxy [302]. He joined the Radiophysics Lab in 1940, and from 1966 to 1987 he worked at the University of Maryland, USA. From 1986–1990 he discovered many optically 'hidden' galaxies, due to obscuring dust, in the Milky Way's "zone of avoidance".

Bengt E. Westerlund (1921–2008: Danziger and Breysacher [303]) obtained his Ph.D. at the Uppsala Observatory, Sweden, in 1953. After a teaching position in France, from 1957 to 1967 he operated the new Schmidt telescope at the "Uppsala Southern Station" at Mount Stromlo Observatory.⁷³ In 1967 he commenced work at the Steward Observatory in the USA, and he later became the European Southern Observatory's director in Chile in 1970. Although his most cited article (included in Table 5) pertains to Population I stars in

⁷⁰ The NASA-run Tidbinbilla Deep Space Communication Complex in Canberra subsequently played a key role in 2012 regarding the successful landing of the Mars rover Curiosity in 'Gale Crater'.

⁷¹ Working with Tony Hewish, M.E. Clarke obtained her Ph.D. from Cambridge, where she had discovered the phenomenon of Interplanetary Scintillations. She subsequently came to Parkes in the mid-1960s.

⁷² Prior to becoming an astronomer at Parkes, J.A. Ekers had obtained a degree in chemistry and conducted medical research.

⁷³ Due to Canberra's light pollution, the Uppsala Schmidt telescope was moved to Siding Spring Observatory in 1982.

the Large Magellanic Cloud [304], he is also well known for the article Westerlund [305] titled “A Heavily Reddened Cluster in Ara” in which he discovered what has come to be called “Westerlund 1”. Furthermore, known as the Ara Cluster, this is the most massive compact young star cluster in our Galaxy and the Local Group. Some think that it may evolve into a Globular Cluster [306]. The cluster also contains “Westerlund 1-26”: a red supergiant that is one of the largest stars we know. The year 2015 marked the silver jubilee (25 years) for the Hubble Space Telescope, and an HST image of “Westerlund 2” (another giant cluster of some 3000 stars, Westerlund [307]) was recently used as an official Hubble 25th Anniversary image (see Figure 4).⁷⁴ Moreover, the Westerlund [308] textbook about the Magellanic Clouds is regarded as something of a bible. Upon his retirement, asteroid “2902 Westerlund” was named in his honour, and in 2004 he inaugurated the “Westerlund Telescope” at the Uppsala Astronomical Observatory.



Figure 4. Westerlund 2 in the Carina Nebula. Credit: NASA, ESA, the Hubble Heritage Team (STScI/AURA), A. Nota (ESA/STScI), and the Westerlund 2 Science Team

Having met J.A. Roberts in Section 3.2 (and A.E. Ringwood in Section 3.3), we are left with **Max M. Komesaroff** (deceased 1988), who reported on the radio polarisation of Jupiter in Roberts and Komesaroff [309], exploring Jupiter’s radiation belt. Komesaroff joined the CSIRO group at Dapto in 1953, and he is also well known for his many CSIRO-badged Nature articles about pulsars, such as: “Spectral Fine Structure in Pulsar Radiation” [310]; “Measurements on the Period of the Pulsating Radio Source at 1919 + 21” [311]; “Evidence in Support of a Rotational Model for the Pulsar PSR 0833-45” [312]; and his theoretical work on the “polar cap” model titled “Possible Mechanism for the Pulsar Radio Emission” [313]. This latter work built on that by Gold [314] and Goldreich and Julian [315], see Section 3.5. Komesaroff [310] involved the pulsating radio source at 1919+21 (known as CP 1919, it was the first pulsar to be discovered: Hewish et al. [316]). A pen-chart recording of its pulses was obtained at Parkes by Brian John Robinson (1930–2004: Whiteoak and Sim [317]) on 8 March 1968 [318,319], and in 1973 this appeared on the Australian \$50 paper note along with an image of the Parkes radio telescope.

3.5. 1966–1969

The brilliant North American **Peter Goldreich** (1939–) obtained his Ph.D. from Cornell in 1963, under Thomas Gold (1920–2004). In 1966 he joined Caltech as an Associate Professor, and he was made a full professor in the year that Goldreich and Julian [315] was published, along with his sole-author Australian publication Goldreich [320] on this same topic. His most cited article, Goldreich & Julian was written during an extended visit to the University of Sydney’s School of Physics in 1969. It explored the physics of a rotating neutron star whose magnetic dipole moment is aligned with the axis of rotation, and the associated slowing of the rotation due to magnetic torques and energy losses to surrounding particles. **William H. Julian** is a fellow North American astronomer who

⁷⁴ This obscured cluster resides in the Gum 29 nebula, in the constellation Carina, also known as RCW 49.

arrived at Caltech the year after Goldreich, and after having penned the important Julian and Toomre [321] article regarding the dynamics and stability of thin, differentially rotating disc galaxies in response to lumpy perturbers and the onset of spiral structure⁷⁵. Julian has since relocated and is now a Professor Emeritus at the New Mexico State University.

Leo John Gleeson (deceased 1979; Westfold [323]) was a key contributor to the theory of cosmic ray modulation. He published a tremendously influential paper [324] with W.I. Axford just as he arrived in the Mathematics Department at Monash University. Although in 1968 they were both affiliated with the University of California, San Diego, Gleeson's "Present address" when the paper came out was Monash University, hence its inclusion here (and on the Monash University's Applied Mathematics web-pages) which some may debate. The pair had two other very well-cited articles in 1967 and 1968. The first is titled "Cosmic Rays in the Interplanetary Medium" [325] and has 300 citations but a Cornell University affiliation in the USA, albeit at their "Cornell-Sydney University Astronomy Center". The second is titled "The Compton-Getting Effect" [326] and has a Monash University and a University of California, San Diego, affiliation, but without enough citations (107) to make it into Table 6. Together with Prof. Robert Street (1920–2013), Dr Denis Walter Coates, and Mr Robert Luke Bryant (Monash Physics Department), Gleeson helped establish the Mount Burnett Observatory in the Dandenong Ranges near Melbourne using a 16-inch reflector purchased from the Bendigo estate of Mr L. Jeffree.

From Dannevirke, New Zealand, **William Ian Axford, Sir** (1933–2010; Vasyliuūnas [327]) was one of the pioneers of space plasma physics. In addition to his work on the origin and acceleration of cosmic rays by shocks, he explained phenomena related to the solar heliosphere, explained how the solar wind couples with the Earth's magnetosphere and ionosphere, and explained how the solar wind interacts with the interstellar medium [328]. He became the Director at the Max Planck Institute for Aeronomy (later MPI for Solar System Research) in 1974. He was the Vice-Chancellor of Victoria University, Wellington, from 1982 to 1985, before returning to MPI for Solar System Research, where he retired in 2001. New Zealand's Ian Axford [exchange] Fellowship in Public Policy is named in his honour.

Venkataraman Radhakrishnan (Rad) (1929–2011) was from India, as were Twiss and Hanbury Brown. He was the son of the 1930 Nobel laureate physicist Sir Chandrasekhara Venkata Raman (1888–1970)⁷⁶, who is famous for "Raman Scattering". After working at Caltech as a Senior Research fellow from 1959 to 1964 (without a Ph.D.), Radhakrishnan sailed across the Pacific in a 35-foot trimaran called⁷⁷ Cygnus A and joined the CSIRO Division of Radiophysics as a Senior Research Scientist in 1965. At Parkes, he found the radio pulse from pulsar PSR 0833-45 to be 95 ± 5 percent polarised, and that the plane of polarisation rotated close to 90° during the pulse [312], with his observations at different frequencies [331] leading him and D.J. Cooke to correctly hypothesise about the rotating magnetic fields and poles of the pulsar. This research followed similar work with rotating magnetic neutron stars by Gold [332] at Cornell University, and Goldreich and Julian [315] from Caltech and later Monash, and Radhakrishnan's own work on the magnetic field and internal rotation of Jupiter [333]. In another work, Radhakrishnan and Manchester [334] reported on a 'change of state' in this pulsar, with the period abruptly decreasing by two parts per million. Radhakrishnan is perhaps equally well known for his series of articles in 1972 titled "The Parkes Survey of 21-Centimeter Absorption in Discrete-Source Spectra" [335]. This built on his 21-cm research portfolio that he started at the Onsala observatory, Sweden, in the late 1950s and which he continued with Bolton in the early-1960s while they were at Caltech together. After Radhakrishnan's father died in 1970, he left the Division of Radiophysics and spent some of 1971–1972 at the Meudon Observatory, France, before returning to India to become the Director of the Raman Research Institute, which had been established by his father in Bangalore. He held this role from 1972 to

⁷⁵ Their model suggests that spiral patterns are transient responses to a lumpy disc, at odds with the standing density wave theory of Lin and Shu [322] which is likely responsible for the 'grand design' spirals.

⁷⁶ The 1930 Nobel physicist Subrahmanyan Chandrasekhar was the nephew of Sir Chandrasekhara Venkata Raman.

⁷⁷ Cygnus A was the first radio galaxy discovered [329,330].

1994, where he successfully continued his research on pulsar astronomy and liquid crystals. He was also the IAU Vice-President from 1988 to 1994. Still without a Ph.D., in 1996 the University of Amsterdam awarded him an honorary doctorate degree.

David (Dave) J. Cooke, a co-author of pulsar papers with Radhakrishnan [311,312,331], graduated with an engineering degree from The University of Adelaide. He worked at the Weapons Research Establishment at Salisbury in South Australia (the base for the Woomera rocket range), where A.J. Shimmins had worked, and at the Radar Research Establishment at Malvern in the UK. Cooke joined the staff at Parkes in 1967, and in 1969 he was the Senior Radio Receiver Engineer on duty during the Apollo 11 lunar landing broadcast around the world, for which he received an award in Houston, Texas, in 2007 (along with an Australia Day “Stars of Australia” award). He was the Officer-in-Charge of the Parkes Observatory from 1988 to 1993.

Lindsey Fairfield Smith attended the Women’s College at the University of Sydney—as had Joan Freeman (Section 3.1)—where she obtained her B.Sc. degree (1958–1961) before then obtaining her Ph.D. from The ANU. She completed her thesis in 1966 and graduated in 1967. In addition to her two 1968 papers [336,337] from Mount Stromlo (listed in Table 6), in that same year, while at the University of Colorado, she published her third important Wolf-Rayet star paper regarding the distribution of those stars in our Galaxy [338]. In 1978 she returned to Australia as a Senior Lecturer in Physics at the University of Wollongong. She then closed the circle by returning to Mount Stromlo in 1989–1991, and by 1993 she was back at the University of Sydney, where she developed a useful three-dimensional classification for nitrogen-dominant Wolf-Rayet stars [339].

Betty ‘Louise’ Turtle, née Webster (1941–1990: Storey and Faulkner [340]) was another graduate student at Mount Stromlo during the Bok years, who was present at the same time as L.F. Smith and supervised by B. Westerlund. After graduating, and while at the University of Wisconsin, Webster authored her own (similarly themed and) popular survey paper titled “The masses and galactic distribution of southern planetary nebulae” [341] which has been cited 115 times. Webster subsequently worked with Sir Richard Woolley (former Director at Mount Stromlo Observatory) at the Royal Greenwich Observatory, including time at the South African Astronomical Observatory, before helping to commission the AAT and working at the newly formed Anglo-Australian Observatory, and then working at the University of New South Wales from 1978 onwards. She has many papers of note, including work on chemical abundance gradients in galaxies and identifying the X-ray binary source Cygnus X1 as a possible black hole [342]. She is largely responsible for having established the Bok Prize, and she herself is honoured through the Louise Webster Prize, which the Astronomical Society of Australia also administer.

Richard (Dick) Xavier McGee (1921–2012: Sim [343]) was a clerk in the Customs Department when he was called up for military service in 1941. He was posted to Darwin, where he was very nearly killed during the 1942 air raid when bombs fell on either side of the truck that he was driving. It is not known to us if he met J.H. Piddington at that point. He later trained as a navigator in Canada and flew in Lancasters in the UK. After the war, in 1947, he quit his job as a clerk (which he had initially returned to) and went to the University of Sydney on a Commonwealth scholarship. He obtained a first-class honours degree in Physics and subsequently worked for CSIRO’s radiophysics laboratory from 1950 until his retirement in 1986. From 1971 to 1988, he was the editor of the Publications of the Astronomical Society of Australia. He is known for his contribution to our knowledge of the Milky Way’s chemical abundance gradient [344], and his detailed HI survey [345] which revealed the distribution and motion of hydrogen gas in the LMC, including a primitive spiral pattern and local fuel supply for the stellar nurseries scattered around the galaxy⁷⁸. **Miss Janice A. Milton** (later Mrs J.A. Weedon) and McGee also published a survey of neutral hydrogen across the southern sky, in addition to their focus on the LMC, which was repeated with the Parkes telescope when its instrumentation improved.

⁷⁸ The survey was so important that it was repeated at Parkes in 1984 [346].

Table 6. The ten most cited articles from 1966 to 1969 are numbered in column 1, and involve 12 distinct authors. Ten distinct authors can be found above the horizontal line.

#	Title	Affiliation	Author(s)	Year	Journal Vol. Page	Cites
1.	Pulsar Electrodynamics	Univ. Sydney & Caltech	Goldreich, P. & Julian, W.H.	1969	ApJ 157, 869	(1660)
2.	Solar Modulation of Galactic Cosmic Rays	UCSD (USA) & Monash University	Gleeson, L.J. & Axford, W.I.	1968a	ApJ 154, 1011	(518)
3.	Magnetic Poles and the Polarization Structure of Pulsar Radiation	CSIRO-Radiophysics	Radhakrishnan, V. & Cooke, D.J.	1969	ApL 3, 225	(498)
4.	A Revised Spectral Classification System & a new catalogue for galactic Wolf-Rayet stars	MSO	Smith, L.F.	1968a	MNRAS 138, 109	(297)
5.	Absolute Magnitudes and Intrinsic Colours of Wolf-Rayet Stars	MSO	Smith, L.F.	1968b	MNRAS 140, 409	(275)
6.	21 cm hydrogen-line survey of the Large Magellanic Cloud. II...	CSIRO-Radiophysics	McGee, R.X. & Milton, J.A.	1966	AuJPh 19, 343	(272)
7.	Chemical evolution of the terrestrial planets	The ANU: Geophys. & Geochem.	Ringwood, A.E.	1966	GeCoA 30, 41	(242)
8.	New subdwarfs. II. Radial velocities, photometry and preliminary space motions for 112 stars with large proper motion	Mount Wilson (USA) & MSO	Sandage, A.	1969b	ApJ 158, 1115	(222)
9.	The Double Cepheid CE Cassiopeiae in NGC 7790...	MSO & Univ. Basel (Switz.)	Sandage, A. & Tammann, G.A.	1969	ApJ 157, 683	(209)
10.	The Reddening, Age Difference, and Helium Abundance of the Globular Clusters...	MSO	Sandage, A.	1969a	ApJ 157, 515	(189)

Allan Rex Sandage (1926–2010: Tammann [347], Devorkin [348], Kennicutt [349], Lynden-Bell and Schweizer [350], van den Bergh [351]) was a hugely influential North American astronomer who obtained his Ph.D. from Caltech in 1953—the year that Edwin Hubble, to whom Sandage was a student assistant, passed away. Sandage spent a year at Mount Stromlo in 1969, and in that time, he wrote three of Australia’s most cited astronomy articles from the latter half of the 1960s [352–354]. Prolific as always, his articles in Table 6 discuss stars with large proper motions, calibrating the cepheid period-luminosity relation (recall the work of [355]), and globular cluster helium abundances and ages [356–358]. In one of astronomy’s longer running debates⁷⁹, Sandage famously advocated [360] a ‘Hubble constant’ of around $55 \text{ km s}^{-1} \text{ Mpc}^{-1}$, while at the same time, de Vaucouleurs (who had been at Mount Stromlo 12–18 years earlier), along with Sidney van den Bergh (1929–), were advocating a higher value around $80\text{--}100 \text{ km s}^{-1} \text{ Mpc}^{-1}$. The disparity led to a “Key Project” on the Hubble Space Telescope, which reported a value of $71 \pm 6 \text{ km s}^{-1} \text{ Mpc}^{-1}$, with a corrected value of $68 \pm 6 \text{ km s}^{-1} \text{ Mpc}^{-1}$ reported by Mould et al. [361]. Sandage also worked on other topics such as cepheid variables and globular clusters as a means to probe the distance scale of the Universe [362]. He is, of course, also known for his research into observational cosmology, the “monolithic collapse” model for galaxies [363]⁸⁰, contributions to the colour-magnitude relation for early-type galaxies [364]⁸¹, and his many galaxy catalogs [366–368].

Gustav Andreas Tammann (1932–2019: Leibundgut [369]) was the director of the University of Basel’s Astronomical Institute in Switzerland. His work with supernovae, the extragalactic distance scale, and the expansion of the Universe has earned him several international medals, and asteroid 18872 Tammann is named after him.

4. Concluding Remarks

By the second half of the 1940s, the more cited astronomical studies (Table 2) focussed on the Sun at radio wavelengths and explored its influence on Earth’s magnetosphere and ionosphere. Indeed, eight of the top-10 and twelve of the top-15, most-cited articles from this period relate to this. Notable at this time were the contributions from several women who did not just capably fill the void that had arisen with so many men away fighting in WWII but who excelled in their roles. In particular, Rachel E.B. Makinson tutored radiophysics at The University of Sydney to RAAF airmen and pre-(radio astronomers) during the war. She eventually went on to study the physics of fibres and advance the wool industry for Australia, following in the footsteps of Elizabeth and John Macarthur, who helped establish that very industry. One of the first radio astronomers to emerge after the war was Ruby Payne-Scott, who had co-developed radar during the war with Joan Jelly, née Freeman, and others. While Joan Freeman switched slightly from radiophysics and went on to become one of the world’s leading nuclear physicists, Ruby Payne-Scott is the author of one of Australia’s most cited astronomy articles from the years 1945 to 1950 (Table 2). As discussed, her work built on that performed by another remarkable woman, Elizabeth Alexander, in New Zealand.

One of the few exceptions to the 1945–1950 articles that were predominantly related to solar phenomena is *the* most-cited article from this period. Written by Prof. ‘Walter’ Stibbs, it pertains to magnetic variability in another star. Together with an article about the detection of three radio-sources beyond our solar system, it signalled how astronomy was starting to branch out. As technology developed over the years, the research expanded to include yet more stars, galactic and extragalactic radio sources, and various other aspects of our Galaxy and neighbouring galaxies. Reflecting this development, the ten most-cited articles from the latter half of the 1960s (Table 6) pertain to eight different topics, including planets, stars, pulsars, globular clusters, cosmic rays, and HI in the Large Magellanic Cloud.

⁷⁹ Tension over the precise value of the Hubble constant continues to this day (e.g., [359]).

⁸⁰ Olin Eggen wrote this paper while at Caltech, but he was later the Director at Mount Stromlo Observatory from 1966–1977. He was reportedly something of a character who drove a Bolwell fibreglass sports car with a Ford V8 motor. He died while visiting Canberra in 1998.

⁸¹ **Natarajan Visvanathan (Vis)** (1932–2001: Faulkner [365]) was a particularly friendly staff member at Mount Stromlo Observatory from 1975 to 2001, often seen driving his yellow Porsche sports car up and down the mountain.

Among the articles from 1966 to 1969 is not one but two articles from Lindsey Fairfield Smith, who had attended the Women’s College at the University of Sydney where Joan Freeman had been two decades earlier. In one of her papers from 1968, Lindsey Smith presented a catalogue for the distribution of Wolf-Rayet stars in our Galaxy⁸², as seen from the Southern Hemisphere. In the following year, Betty ‘Louise’ Turtle, née Webster—another Ph.D. student at Mount Stromlo Observatory under Bart J. Bok’s Directorship—published on the Galactic distribution of southern planetary nebulae.⁸³ It should be remembered that contributing to the apparent 20-year hiatus of women in our Tables was society in general. Married women were expected to look after the house; until 1966, they were denied permanent jobs in the Australian Public Service and were fired if they became pregnant. Provisions for (unpaid) maternity leave within the Public Service did not arrive until 1973, and the concept of equal pay for equal work did not come into practice until the 1970s (since 1950, it had been at 75 percent of the male basic wage). However, helping to turn the tide was the husband and wife team of Bart J. Bok (Director) and Priscilla F. Bok (astronomer), known for increasing the number of female Ph.D. astronomy students at Mount Stromlo Observatory. They arrived the year that the wife and husband team of Antoinette and Gerlad H. de Vaucoulers left (after six years at Mount Stromlo Observatory). More recently, this century, there has been another couple at the Observatory, but with a nice reversal. There was a female Director (Penny D. Sackett) with her partner astronomer (Frank H. Briggs).

Although working as either paid professionals or as funded students, the individuals appearing in Tables 2–6 almost certainly did not achieve their success by only working from 9 to 5. They undoubtedly, and literally, worked day and night to render their valuable service for the credit of Australia and the advancement of astronomical science. It is appropriate that their labours are remembered here and elsewhere. Of exceptional distinction are three names in the preceding Tables. J.P. Wild appears in the first four tables spanning two decades, while A.E. Ringwood appears in the last three tables. Based on his analysis of lunar rocks returned by Neil Armstrong, Buzz Aldrin, Michael Collins and the Apollo missions, Ringwood later advanced the theory that our Moon was split-off from an early-Earth. Finally, E.E. Salpeter has four very highly cited articles, taking out the first and second, and first and third, spots in two different tables⁸⁴.

While not included in the above tables of scientific research articles, the year 1969 is, of course, also memorable for the valuable role that Australia played in receiving and broadcasting the Apollo 11 lunar landing to the world (see Figure 5). This historic event will likely be remembered for centuries to come; it was when humankind’s exploratory nature culminated in us leaving our planet and walking on another astronomical body. Neil Armstrong’s stepping onto the Moon, footage of which was captured by the engineering team at the 26 m dish at the Honeysuckle Creek⁸⁵ NASA tracking station in Canberra⁸⁶, along with the subsequent footage (after the initial 8 min) involving Buzz Aldrin and taken by the team at the Parkes Observatory, was relayed around the world. The large 64 m Parkes radio telescope continues to conduct world-leading research today. Examples include: the Parkes Pulsar Timing Array (PPTA) to detect the presence of long-wavelength gravitational radiation [373–376]; the search for fast radio bursts (FRB: [377,378]); a survey of methanol masers at 6.7 and 12.2 GHz [379,380]; and the exciting ‘Breakthrough Listen’ project [381] expanding upon the 1995 Search for Extra-Terrestrial Intelligence (SETI) ‘Project Phoenix’ [382] in which then-PhD student A.Graham was one of the Official Observers.

⁸² Still a popular subject, Neugent and Massey [370] provide an update for our Local Group.

⁸³ Following Webster’s pioneering work, Gaia has enabled distances to over 1000 planetary nebulae González-Santamaría et al. [371].

⁸⁴ Had we extended the tables slightly further, we note that J.H. Piddington would also have featured in every Table.

⁸⁵ [http://members.pcug.org.au/\\$\sim\\$mdinn/TheDish/](http://members.pcug.org.au/\simmdinn/TheDish/) (accessed 29 March 2021).

⁸⁶ This historic telescope was later relocated to Tidbinbilla, Canberra, where NASA’s 70 m dish operates [372] (pp. 501–503).

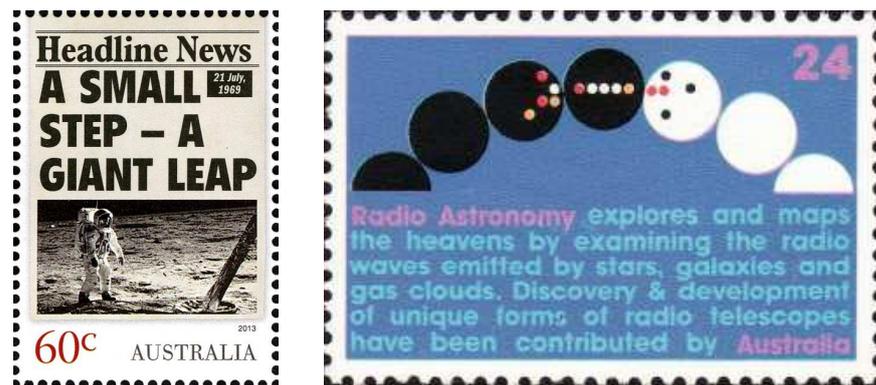


Figure 5. Left panel: Australia Post stamp from the 23 July 2013 “Headline News” series, showing the lunar footage taken from Australia on 20 July 1969. Right panel: Australia Post stamp from the 14 May 1975 “Scientific Development” series.

4.1. Looking Forward

From 1955 to 1974, until the 3.9 m telescope opened at Siding Spring Observatory, the 74-inch (1.9 m) telescope at Mount Stromlo Observatory, together with the 1950-opening of the 74-inch Radcliffe Telescope [383] in Pretoria, South Africa, were the largest optical telescopes in the Southern Hemisphere, giving these two countries a unique vantage point. With the Square Kilometer Array (SKA)⁸⁷ to be located in both Australia and South Africa, these two countries will again host a large telescope. This time a radio facility two orders of magnitude more sensitive and rapid in sky surveys than present radio facilities.⁸⁸ Due to Australia’s lack of high mountains, it is not an optimal site for a large, next-generation optical/infrared telescope [385]. Ongoing access to such a telescope, in particular the Giant Magellan Telescope (GMT)⁸⁹ in Chile [386], is, of course, recognised as key to the ongoing success of astronomy in Australia. As such, Australia is a partner in this grand venture. Indeed, not one but three such giant telescopes are under development by different groups worldwide due to the wide-spread desire for access to such a facility given the ground-breaking scientific questions that they can tackle.

Investment today, in new facilities and instruments for existing telescopes, promises to secure Australia’s astronomical future, such as the international Murchison Widefield Array (MWA⁹⁰) [387–389] in Western Australia and the Australian Square Kilometre Array Pathfinder (ASKAP: [390–394]) also sited at the Murchison Radio-astronomy Observatory (MRO) in Western Australia. The long-wavelength MWA operates at frequencies of 70–300 MHz, and can study the Sun [395,396], as previously done at The University of Western Australia after WWII [397]. It will additionally enable studies of the Earth’s ionosphere, variable radio sources, neutral atomic hydrogen at the epoch of reionisation, and more [398–402]. This follows the successes of earlier low-frequency antennae in Sydney, Tasmania [403,404], and also near Adelaide. The University of Adelaide’s Buckland Park Array, which at 1 square km in size, was the world’s largest low-frequency telescope when it was finished in 1969. In the northern hemisphere, the Caltech-operated Long Wavelength Array (LWA⁹¹) at the Owens Valley Radio Observatory, California, currently operates at 28 MHz to 88 MHz and has the same science goals as the MWA, as does the SKA-pathfinder Low-Frequency Array (LOFAR⁹²), built by the Netherlands Institute for Radio Astronomy, ASTRON.

⁸⁷ www.skatelescope.org (accessed 29 March 2021).

⁸⁸ The Chinese have constructed the behemoth “Five hundred meter Aperture Spherical Telescope (FAST: [384]) in Pingtang County, Guizhou Province, which will also contribute tremendously to furthering our knowledge of the Universe.

⁸⁹ www.gmto.org (accessed 29 March 2021).

⁹⁰ <http://mwatelescope.org> (accessed 29 March 2021).

⁹¹ <http://www.tauceti.caltech.edu/lwa> (accessed 29 March 2021).

⁹² <http://www.lofar.org> (accessed 29 March 2021).

Although not national facilities, smaller aperture, optical telescopes such as The ANU's automated 1.35 m SkyMapper telescope [405–407] at Siding Spring Observatory, the 1 m fast-slew robotic Zadko Telescope⁹³ at the Gingin Observatory near Perth [408], and the Hungarian-made Automated Telescope Network-South (HATSouth) unit looking for exo-planets from Siding Spring Observatory [409], are also expected to deliver many exciting discoveries. Interestingly, 60-odd years ago, a 13 cm patrol telescope operated daily at the Culgoora Solar Observatory near Narrabri as a part of a worldwide network watching for solar flares. This supported the USA space programme and was funded by the USA National Oceanic and Atmospheric Administration. The observations were to support NASA's Skylab, which, ironically, crash-landed in Australia because of solar flares that had heated our upper atmosphere and which subsequently expanded and thus increased the wind drag on Skylab. Regular solar observations for monitoring space weather and ionospheric conditions are still made today from Culgoora, and many other places, such as Learmonth in Western Australia. Learmonth additionally hosts one of the six Global Oscillations Network Group (GONG) instruments that provide helioseismic doppler data, magnetograms, and H α images of the Sun. Radar is also used to study the ionosphere and aurora from Tasmania via the Tasman International Geospace Environment Radar (TIGER⁹⁴) team within the Space Physics Group at La Trobe University [410].

Of course, Australia's reputation for astronomy is no longer just based on optical and radio (including millimetre) observations. Much of Australia's research is now enabled by access to significant computing power, off-shore facilities, and space-based satellites that have genuinely opened up astronomy. This research encompasses areas such as: wide-field, high-spatial-resolution optical studies not feasible from the ground; infrared astronomy⁹⁵; ultra-violet research⁹⁶; X-ray studies⁹⁷; and the gamma-ray universe. In addition, atmospheric particle showers from cosmic rays⁹⁸ [411,412] also contribute to Australia's broad and rich astronomical research portfolio.

Rather like radio physics in the late 1940s, gravitational wave physics in Australia has expanded from physics into astronomy, especially after the detection of gravitational radiation from coalescing black holes [413]. This area of research holds much promise, and many Australian researchers now have involvement with the large overseas ground-based facilities searching for gravitational radiation [414] and any associated electromagnetic counterpart [415,416]. Work is currently conducted at The Australian International Gravitational Research Centre based at The University of Western Australia, within the OzGrav Centre of Excellence⁹⁹ funded by the Australian Research Council, and elsewhere. There are also indirect searches occurring in Australia through the Parkes Pulsar Timing Array mentioned earlier, and many other astronomers in Australia have written theoretical papers on the subject.

Further afield, the gold mine¹⁰⁰ in the town of Stawell—where the unique sundial of astronomer Charles James Merfield (1866–1931) can be found—has connections with astronomy via the search for the Universe's alleged but elusive *dark matter* [54,417–420].

⁹³ <http://www.zt.science.uwa.edu.au> (accessed 29 March 2021).

⁹⁴ <http://www.tiger.latrobe.edu.au/> (accessed 29 March 2021).

⁹⁵ In the 1960s, the Australian Government's Department of Supply was involved with infrared mappings of the sky using balloon-borne detectors.

⁹⁶ Ultra-violet observations of the Sun were made by The University of Adelaide in collaboration with the Weapons Research Establishment at Salisbury using rockets and satellites. An ultra-violet telescope named Endeavour was built at Mount Stromlo Observatory by Auspace Ltd. It flew aboard the space shuttle Discovery (flight STS 42) in January 1992 and took observations from the space shuttle Endeavour (STS 67) in March 1995, along with the USA's ASTRO-2 UV program.

⁹⁷ In the late 1960s, X-ray astronomy was conducted by the University of Tasmania and The University of Adelaide from sounding rocket and balloon payloads launched from Mildura.

⁹⁸ Such studies have been conducted at The University of Adelaide since the early 1970s.

⁹⁹ <https://www.ozgrav.org> (accessed 29 March 2021).

¹⁰⁰ Arete Capital Partners own the Stawell Gold Mine.

While the astronomical connections with the esteemed Fairfax and Packer families have largely disappeared¹⁰¹, new connections seem hopeful with the Australian Government's recent (1 July 2018) creation of the Australian Space Agency headquartered in Adelaide. Business leaders come philanthropists, such as Stanley Chatterton who co-founded Woolworths (sponsor of the Stawell Gift foot race) and enabled the Chatterton Astronomy Department at The University of Sydney, have in the past supported scientific investigations of discovery. While most astronomical facilities in Australia are still simply named after their location—just a few are named after pioneering astronomers, such as the Paul Wild Observatory in Culgoora—, Australia is starting to see naming rights awarded to individuals recognised for their support of astronomy. The Zadko Telescope¹⁰², which opened in 2009, is perhaps the first such facility. Another example is the W.M. Keck Observatory's¹⁰³ Remote Observing Facility at the Swinburne University of Technology, affectionally known as the Baker Control Room after it was partially funded through a generous donation from the Eric Ormond Baker Charitable fund. While more such partnerships would be heartily welcomed, it is clear that Australia has the drive, talent, and potential to continue in the footsteps of its pioneering astronomers.

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Appendix A. Further Reading

During our research, we encountered several informative books about astronomy in Australia over the past century. This led us to search for more books, and while we do not confess to having read or reviewed the following, we nonetheless felt that we could list and acknowledge them here for the benefit of readers who may wish to explore this topic further.

- **1987**, C.B. Schedvin, *Shaping Science and Industry: A History of Australia's Council for Scientific and Industrial Research 1926–1949*, Allen & Unwin.
- **1990**, S.C.B. Gascoigne, K.M. Proust & M.O. Robins, *The Creation of the Anglo-Australian Observatory*, Cambridge University Press.
- **1991**, R.S. Bhathal & Graeme White, *Under the Southern Cross: a brief history of astronomy in Australia*, Kangaroo Press, Kenthurst, NSW.

¹⁰¹ The prestigious Fairfax Prize still exists; it is awarded to first-year students at The University of Sydney who receive the highest possible entrance score.

¹⁰² The 1 m Zadko Telescope was made possible through a generous donation from businessman James Zadko to The University of Western Australia.

¹⁰³ <http://www.keckobservatory.org/> (accessed 29 March 2021).

- 1992, Peter Robertson, *Beyond Southern Skies: Radio Astronomy and the Parkes Telescope*, Cambridge University Press.
- 1993, Kerrie Dougherty & Matthew L. James, *Space Australia: The Story of Australia's Involvement In Space*, Powerhouse Publishing.
- 1994, D.E. Goddard & D.K. Milne (Eds.) *Parkes: Thirty Years of Radio Astronomy*, CSIRO Publishing.
- 1996, Raymond Haynes, Roslynn Haynes, David Malin & Richard McGee, *Explorers of the Southern Sky: A History of Australian Astronomy*, Cambridge University Press.
- 1996, Ragbir Bhathal, *Australian Astronomers: Achievements at the Frontiers of Astronomy*, National Library of Australia Publishing, Canberra.
- 2003, T. Frame & D. Faulkner, *Stromlo: An Australian Observatory*, Sydney, Allen & Unwin.
- 2004, Nick Lomb, *Transit of Venus: the Scientific Event that Led Captain Cook to Australia*, Sydney, Powerhouse Publishing.
- 2008, Roslyn Russell, *Two People & a Place: The Family Who Lived in Sydney Observatory*, Yarralumla, A.C.T., Roslyn Russell Museum Services.
- 2009, Woodruff T. Sullivan III, *Cosmic Noise: A History of Early Radio Astronomy*, Cambridge University Press.
- 2010, Miller Goss & Richard McGee, *Under the Radar: The First Woman in Radio Astronomy: Ruby Payne-Scott*, Springer.
- 2011, Richard Gillespie, *The Great Melbourne Telescope*, Read How You Want.
- 2011, Nick Lomb, *Transit of Venus: 1631 to the Present*, University of New South Wales Press.
- 2013, Miller Goss, *Making Waves: The Story of Ruby Payne-Scott: Australian Pioneer Radio Astronomer*, Springer.
- 2013, Ragbir Bhathal, Ralph Sutherland & Harvey Butcher, *Mt Stromlo Observatory: From Bush Observatory to the Nobel Prize*, CSIRO Publishing.
- 2013, David P.D. Munns, *A Single Sky: How an International Community Forged the Science of Radio Astronomy*, The MIT Press.
- 2017, R.H. Frater, W.M. Goss, H.W. Wendt, *Four Pillars of Radio Astronomy: Mills, Christiansen, Wild, Bracewell*, Springer International Publishing AG.
- 2017, P. Robertson, *Radio Astronomer John Bolton and a New Window on the Universe*, NewSouth Publishing.
- 2021, W. Goss, C. Hooker, R. Ekers, *From the Sun to the Cosmos - Joseph Lade Pawsey, Founder of Australian Radio Astronomy*, in preparation.

Appendix B. Update

Based on (a medley of) metrics, rankings of articles, journals (e.g., <https://www.scimagojr.com>, accessed 29 March 2021), Universities (e.g., <http://www.shanghairanking.com>, accessed 29 March 2021), and even the world's top 2% of scientists [421] will change with time. Since this research was conducted, the various papers have jostled around slightly in the Tables. Of note are the following changes.

From the 1945–1950 time period, three ‘new’ publications have appeared on the horizon, the most prominent of which is (‘Relative Times of Arrival of Bursts of Solar Noise on Different Radio Frequencies’ Payne-Scott et al. [422]), coming in at number 10. One new name from this three-author publication is **Donald (Don) E. Yabsley**, who was involved in many pioneering, multi-frequency, solar radio astronomy experiments around Sydney. He also led the Division of Radiophysics’ 1949 expedition in Tasmania to observe a partial eclipse of the Sun [423]. The two other ‘new’ publications are ([424], ‘Chromospheric Flares’) and ([425], ‘Variable Source of Radio Frequency Radiation in the Constellation of Cygnus’), which now enter the tail (10 to 15) of the list, and are written by authors whom we have already encountered.

From the 1951–1955 time period, citations to the top-ranked paper [142] have increased by nearly a half, while citations to O’Connell [209] have more than doubled, catapulting it from 12th to 7th.

From the 1956–1960 time period, citations to Bracewell [189] have increased by nearly a half, moving it from 9th to 4th. Three ‘new’ publications have also appeared on the radar, the most prominent of which is (Oort et al. [302], ‘The galactic system as a spiral nebula (Council Note)’), entering the list at number 7. This is a curious publication in that the three authors (J.H. Oort, F.J. Kerr & G. Westerhout) provide no affiliation. It is the authorship of F.J. Kerr and the contribution of radio data from Australia which reveals this is partially an Australian publication. Jan Hendrik Oort (1900–1992: [426–428]) was an eminent Dutch astronomer, and Gart Westerhout (1927–2012: [429]) was a Dutch-American astronomer. Furthermore, now *just* outside the top-ten are (Roberts [201], ‘Solar Radio Bursts of Spectral Type II’) and (Kerr [156], ‘A Magellanic effect on the galaxy’) by authors we have met. From 1961 to 1965, citations to the ‘new’ publication ([430], ‘A Low Resolution Hydrogen-line Survey of the Magellanic System. II. Interpretation of Results’) are up over 40 percent and it is now equal tenth with the prior entries 10 and 11. We have already met the co-authors F.J. Kerr and R.X. McGee, while J.V. (Jim) Hindman is new. Hindman started work at the CSIRO Division of Radiophysics with Jack H. Piddington and as an assistant to W.N. (Chris) Christiansen [71,431,432] in the late 1940s and early 1950s [433]. Hindman went on to co-publish 17 refereed articles up until 1970.

From 1966 to 1969, citations to the ‘new’ publication (Hindman [434], ‘A high resolution study of the distribution and motions of neutral hydrogen in the Small Cloud of Magellan’) are up 10 percent and it is now equal tenth.

All of the 8 ‘new’ entries mentioned above were authored at the CSIR/CSIRO Division of Radiophysics, except for the publication from Giovanelli at the Division of Physics. This is a testament to the longevity of their pioneering research in what was then the nascent field of radio astronomy.

Table A1. New Entries.

Title	Affiliation	Author(s)	Year	Journal
Relative Times of Arrival of Bursts of Solar Noise	CSIR, Div. Radiophysics	Payne-Scott, R., Yabsley, D.E. & Bolton, J.G.	1947	Nature, 160, 256
Variable Source of Radio Frequency Radiation in the Constellation of Cygnus	CSIR, Div. Radiophysics	Bolton, J.G. & Stanley, G.J.	1948	Nature, 161, 312
Chromospheric Flares	CSIR, Div. Physics	Giovanelli, R.G.	1948	MNRAS, 108, 163
The galactic system as a spiral nebula	...	Oort, J.H., Kerr, F.J. & Westerhout, G.	1958	MNRAS, 118, 379
Solar Radio Bursts of Spectral Type II	CSIRO, Div. Radiophysics	Roberts, J.A.	1959	AuJPh, 12, 327
A Magellanic effect on the galaxy	CSIRO, Div. Radiophysics	Kerr, F.J.	1957	AJ, 62, 93
A Low Resolution Hydrogen-line Survey of the Magellanic System. II...	CSIRO, Div. Radiophysics	Hindman, J.V., Kerr, F.J. & McGee, R.X.	1963	AuJPh, 16, 570
A high resolution study of the distribution and motions of neutral hydrogen in the [SMC]	CSIRO, Div. Radiophysics	Hindman, J.V.	1967	AuJPh, 20, 147

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