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Golden Years of Australian Radio Astronomy

An Illustrated History

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Cover image: Chris Christiansen and the solar grating array used to produce radio maps of the Sun. The array was located at the Potts Hill field station, one of a number of sites in and around Sydney operated by the Radiophysics radio astronomers. Credit: CSIRO Space and Astronomy

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Australia’s history was linked with astronomy from the start – Captain Cook’s first voyage was as much to observe the 1769 transit of Venus across the solar disc in Tahiti as it was to explore for *Terra Australis Incognita*, leading to the discovery of Australia’s eastern coast the following year. But 175 years would pass before Australians became part of the first rank of world astronomical research. And when this happened, from cliff edges only a few miles removed from Cook’s landing site at Botany Bay, it was in a most unlikely manner, for they did their astronomy not with glass lenses, but with rods of metal.

Woody Sullivan, 1988

Foreword

Following the end of the Second World War, scientists and engineers from Allied countries adopted their newly acquired skills and instrumentation to a variety of research programs in basic science. But with growing pressures from the escalating Cold War conflict, military patronage remained an important component of the research enterprise, particularly in the United States. Sparsely populated Australia, with limited resources, could not compete with the big American and European programs in atomic and nuclear physics, and focused its national efforts toward the new science of radio astronomy.

The *Golden Years of Australian Radio Astronomy – An Illustrated History* is an extraordinarily detailed and well documented account of the beginnings of radio astronomy at the Australian CSIRO Radiophysics Laboratory (RP). It describes the semi-independent, and sometimes competitive, pioneering work done at a variety of field stations, mostly located in the Sydney suburbs. Separate research groups were led by Bernie Mills, Chris Christiansen, John Bolton, Frank Kerr, Paul Wild, and others, all under the leadership of Joe Pawsey. None of them had any background in astronomy and, with the exception of Pawsey, most of the Radiophysics scientists and engineers had no postgraduate degrees. However, they not only made major discoveries that changed the course of astronomy, they also developed the new techniques of interferometry and synthesis imaging, the cross-type array later known as the Mills Cross, radio polarimetry, and the solar radiospectrograph, each of which became a basis for radio astronomy research for decades to come. The RP staff all had backgrounds in radio physics, mostly gained from their wartime radar activities. Generally, their lack of familiarity with astronomy was not an impediment to discovery, although there were some stumbling incidents, such as when Bolton, Stanley and Slee argued that M87 and NGC 5128 were Galactic objects, rather than accept the extraordinary radio luminosity implied by their extragalactic origin. Nevertheless, they are credited as reporting the discovery of radio galaxies.

Radio astronomy was a new field of research, and the discoveries came quickly, covering widely divergent topics of the Sun and planets, as well as Galactic and extragalactic astronomy. Among the new research areas were: the demonstration that radio source variability was not intrinsic but due to the ionosphere, the first radio surveys of the southern sky, the separate populations of Galactic and extragalactic sources, the first observations of radio source spectra validating their non-thermal origin, the discovery of the Galactic Centre radio source and the first radio supernova remnants, the discovery of radio galaxies with their unprecedented luminosity, the measurement of the angular size of radio sources, the 21 cm delineation of Galactic spiral arms and galactic kinematics, the relation between solar radio emission and sunspot activity, as well as the classification of solar radio bursts. These all helped to bring Australian science to the global stage.

The astrophysical discoveries at RP were accompanied by major developments in instrumentation and techniques that would provide the seeds for new generations of radio telescopes, in Australia as well as world-wide. During this period, an intense rivalry developed between Radiophysics and the radio astronomy group at Cambridge University in Great Britain. The Cambridge group, which consisted primarily of research students, was led by the brilliant, but perhaps somewhat paranoid and secretive Martin Ryle. There were two components to the Cambridge–Sydney rivalry, one based on the interpretation of radio source counts, and the other, lasting until today, involves credit for the development of what Cambridge called "aperture synthesis" and Sydney called "earth rotation synthesis."

In 1955, Martin Ryle made the remarkable announcement that the Cambridge 2C survey showed a huge excess of weak radio sources when compared to a uniform distribution in space. This meant that at large distances there were either more radio sources or that the sources were more luminous. Either way, this implied dramatic cosmic evolution in stark contrast to the expectation of the popular Steady State theory, promoted by Fred Hoyle and others, which required that the Universe be everywhere the same. But a similar sky survey made by the Sydney group, using the Mills Cross, showed no such excess, and indeed did not even confirm the existence of most of the Cambridge sources. Moreover, as the Australian scientists showed later, the Cambridge analysis was faulty, leading to a bias in estimating the number density of weak radio sources, and the Australians argued that their source counts were consistent with the Steady State cosmology. Modern radio source counts are much closer to the Sydney counts than the Cambridge counts, and it is now recognised that most of the sources in the Cambridge 2C catalogue were spurious. Sydney had much better data but got the wrong answer. Cambridge had bad data and didn't understand the effects of noise and confusion, but apparently got the right answer: We do live in an evolving Universe with a finite age, as dramatically verified by the 1965 discovery of the cosmic microwave background by Arno Penzias and Bob Wilson (a former PhD student of John Bolton).

Martin Ryle later received the 1974 Nobel Prize in Physics for the development of high angular resolution radio imaging using multiple interferometer spacings and the rotation of the Earth, a technique they called "aperture synthesis." Ryle's techniques, which were inspired by Cambridge crystallographers, built on the classic Radiophysics paper by McCready, Pawsey and Payne-Scott, who recognised the Fourier Transform relation between the radio interferometer spatial frequency response and the celestial radio image.

But even before the Cambridge work, Christiansen used his cross array to form two orthogonal fan beams. As the Earth rotated, the two fan beams scanned the Sun at different angles. Fourier transforms of the strip distributions were combined using a two-dimensional transform to obtain an image of the Sun. Was this "earth rotation synthesis" as Christiansen later claimed? Why didn't he use the individual interferometer pairs to obtain his Fourier components as Ryle later did? Perhaps, unlike the Cambridge group, he did not have access to the necessary computing power, although as mentioned in Chapter 1, CSIRAC was then one of the most powerful computers in the world, and was located in the same building as Radiophysics. Or perhaps, as an engineer, Christiansen, like Mills with *his* cross array, was more comfortable with a hardware solution than the software solution so effectively implemented later by Ryle and his colleagues at Cambridge.

There was also a certain level of rivalry within Radiophysics bolstered by the competition for resources and for personal recognition. People did not hesitate to criticise the work of other Radiophysics colleagues – but never in print, as Joe Pawsey's steady hand apparently kept the internal rivalry from getting out of hand.

Golden Years of Australian Radio Astronomy is enhanced with almost 300 historical photographs and line drawings, most of which are taken from the CSIRO Radio Astronomy Image Archive (CRAIA) maintained by the Australia Telescope National Facility. There are also short biographical notes on the many personalities that played a key role in the early Australian radio astronomy programs. Perhaps most remarkable of the many distinguished Radiophysics scientists was Bruce Slee, who started his career in 1945 as a radar operator in Darwin with an independent discovery of solar radio emission, as well as an independent recognition of the sea interferometer effect. Seventy years later, he was still active and had more than 200 publications reporting radio studies of the ionosphere, the Sun, Jupiter, comets, radio stars of all types, radio galaxies and normal galaxies, planetary nebulae, exoplanets, quasars, x-ray sources, pulsars, the Galactic Centre, the interstellar medium, and clusters of galaxies, in addition to many first-hand reports on the history of radio astronomy in Australia. Slee probably had the longest scientific career of any radio astronomer, or perhaps any astronomer, and was equally at ease using filled aperture antennas or interferometry, including VLBI. I was privileged to co-author one paper with Bruce, along with Wayne Orchiston, about the life and career of Gordon Stanley.

The authors of *Golden Years of Australian Radio Astronomy* are well qualified to tell the story. Wayne Orchiston worked at RP from 1961 to 1968, the period described in *Golden Years* as "the changing of the guard", and knew most of the RP scientists and engineers who had remained active during this period. He has published dozens of papers on the history of radio astronomy in Australia, France, India, Japan, New Zealand, and the United States. Peter Robertson was the editor (1980–2001) of the *Australian Journal of Physics*, which published the great majority of RP research papers during the period covered in *Golden Years.* Peter is also the author of *Radio Astronomer – John Bolton and a New Window on the Universe*, about one of the heroes of *Golden Years*. Woody Sullivan, who is the author of *Cosmic Noise*: *A History of Early Radio Astronomy* and other books that document the early worldwide history of radio astronomy, brings his expertise and extensive historical knowledge to *Golden Years*.

I spent two years as a young Research Officer (the lowest rung on the CSIRO scientific appointment ladder) at RP between 1963 and 1965. I had started my PhD studies under John Bolton, but he left Caltech just as I was starting my thesis research, and I continued with Gordon Stanley as my supervisor. After finishing my PhD at Caltech, I followed Bolton to Australia, where I lived at Parkes and came to know many of the RP scientists and engineers discussed in *Golden Years.* However, by the time I arrived at RP in September 1963, Bernie Mills and Chris Christiansen had already departed for Sydney University, along with some of the key RP technical staff, and Joe Pawsey had died. We were not encouraged to fraternise with the RP deserters, and although their offices were nearby, we had virtually no contact. I met Taffy Bowen only a few times; once, shortly after I arrived in Australia, when John introduced us, and later when he threw me off the Parkes telescope control console in order to have his picture taken at the controls. I did get to know him better when he later served as the Australian Scientific Attaché in Washington.

My time at RP coincided with what the authors of *Golden Year*s describe as the second phase of Australian radio astronomy. The Parkes radio telescope, known as the Giant Radio Telescope (GRT), was just coming into full operation. John Bolton had moved to Parkes to take day-to-day control of the operation. The field stations, described in Chapter 2, were mostly gone, and the RP radio astronomy research program had become concentrated around the new Parkes 210 foot (64 m) dish. Everyone had their own research program, or formed small teams. The field station culture of the early years carried over to Parkes, with many of the groups building their own receivers or other instrumentation. Observers, even myself as a junior staff member, did not hesitate to rip apart a piece of suspected malfunctioning equipment in the middle of the night in order to implement a hasty ad-hoc repair.

During those early years, there was no competition for observing time and few external observers. Each group of RP scientists indicated what they wanted to do, and agreed on a division of observing time. Living at Parkes, I could squeeze in extra observing time between other scheduled projects or during holidays when others remained in Sydney to be with their families. However, Bolton was firm in reserving daytimes for maintenance even when no maintenance was planned – until I argued that I wanted to observe Mercury.

As an example of the freewheeling culture at Parkes, I was the assigned observer when news arrived from the US about the detection of the 18 cm spectral line of hydroxyl. Bolton and Gardner worked all day and into the night to convert a 21 cm paramp receiver to 18 cm and then threw me off the telescope so that they could observe OH from the Galactic Centre. After a hasty analysis of their data, they quickly dashed off a letter to *Nature*. I had a perverse satisfaction when it turned out that they had mistakenly interpreted the deep Galactic Centre absorption line as an instrumental baseline error.

The final chapter *Where did it all Lead?* gives a brief summary of the major changes in facilities, sites, and culture that followed the pioneering years after 1960. First came the Parkes 210 foot promoted by Taffy Bowen, then Paul Wild's solar

Radioheliograph at Culgoora, followed by Chris Christiansen's Fleurs Synthesis Telescope, and Bernie Mills' SuperCross at Molonglo. These four projects ushered in the era of "big science" and the demise of the semi-autonomous field station culture. The 1980s saw the Australia Telescope Compact Array become a national facility, the conversion of the SuperCross to the Molonglo Observatory Synthesis Telescope (MOST), and the increasing use of radio astronomy facilities by scientists and students from other than RP or the University of Sydney.

The book concludes with speculations about the future of radio astronomy in Australia and the role of the ambitious Square Kilometre Array project. As the authors remark, although the first germs of the SKA came from Europe, for more than a decade the leadership of this growing international project, the recruitment of international partners, and the guidance of the international governance structure was centred in Australia. With an ideal radio quiet site in a remote part of Western Australia, highly regarded expertise and experience in radio astronomy, particularly in the sophisticated area of synthesis imaging, a well-established national infrastructure, and recognised political, social, and economic stability, Australia seemed the logical choice to build and operate the SKA. South Africa had none of these attributes, except radio quiet sites. But with unreserved enthusiasm and optimism that the international SKA would be built in Australia, CSIRO encouraged the interest and later a proposal from South Africa, thinking this would help promote the visibility and credibility of the increasingly expensive international project.

Two so-called SKA 'pathfinders' (ASKAP – the Australian SKA Pathfinder and MWA – the Murchison Widefield Array) were built in Western Australia, as well as one in South Africa (MeerKat). However, as described by the authors, the final decision to split the SKA between South Africa and Australia was a great disappointment for Australian radio astronomers. Whether or not this surprising and unexpected decision was the result of a concern that, if the SKA were located in Australia, there might be a diminished role for the other countries remains a matter of speculation. With the increasing costs and descoping of the SKA, along with uncertain international funding, ASKAP and the MWA themselves may well be the basis of an exciting future for Australian radio astronomy.

Charlottesville, Virginia — Ken Kellermann

Preface

Thinking back, we should thank Bruce Slee for the appearance of this book. Bruce was one of the pioneers of Australian radio astronomy and was a champion of amateur–professional collaboration in astronomy. When the first author of this book (WO) formed the North Shore Astronomical Society (NSAS) in mid-1959, soon after moving from New Zealand to Sydney, Bruce became a strong supporter of this group of teenage amateur astronomers. Subsequently, one of the projects he devised was for groups of Sydney amateur astronomers to carry out visual monitoring of selected dMe flare stars while he observed them with radio telescopes, searching for radio emission that correlated with optical flares. I led one of these groups, and the Director of Sydney Observatory Dr Harley Wood (who also was a strong supporter of the NSAS) allowed us access to a beautiful old 6-inch refractor that was housed in one of the Observatory's domes.

Then, when I completed secondary school in late November 1961, somehow Bruce Slee had convinced his employers, the CSIRO Division of Radiophysics (henceforth RP) to award me a two-month Vacation Assistant position. It was years later that I discovered that only two of these highly sought after positions were awarded annually, and normally to university students who had already completed MSc degrees and were about to begin their doctoral research. To award one to an 18-year old straight out of secondary school was unheard of.

The two-month position was an amazing experience, and one that was destined to shape the rest of my life and – ultimately – lead to this book. Each day I joined Bruce and two RP technicians and we headed to the Fleurs field station at an old WWII air strip just west of suburban Sydney. My job was to assist Bruce with his work, and at the same time learn about radio astronomy – for as an amateur astronomer committed to optical observing my knowledge of radio telescopes and radio astronomy was negligible (a little like Bruce and his colleagues, who as radio engineers and technicians, had been forced to learn astronomy back in the mid to late 1940s).

I enjoyed that short Fleurs 'apprenticeship' immensely, and came to understand something of the Shain Cross that Bruce, Charlie Higgins and I were using for our observations. But more than this, I learnt about the awe-inspiring discoveries that had been made earlier at Fleurs, and at other RP field stations scattered around suburban Sydney. Dover Heights, Hornsby Valley and Potts Hill all became familiar names, along with Dapto near the industrial city of Wollongong to the south of Sydney. Then all-too-quickly the two-month vacation position came to an end. But I must have made an impression because RP decided to employ me full-time, and they offered me a position as a Technical Assistant. As someone without any academic qualifications I was at the very bottom of the 'employment ladder', but that did not matter – I could continue to work in radio astronomy, and I could learn more about the achievements that by 1962 had made RP a world leader in this newly emerging field of science. The only downside was that I was assigned to the Solar Group, and could only collaborate with Bruce when he needed an assistant during observing sessions on the Parkes Radio Telescope (after the various RP field stations had been closed down). But that did not matter because I also was vitally interested in solar astronomy.

Now let us step forward almost 40 years, to 2000. Armed with a PhD and after an academic career in Melbourne and New Zealand I returned to Sydney where Ron Ekers decided to employ me as Archivist and Historian at the Australia Telescope National Facility (ATNF), the successor to RP. One of my responsibilities was to research the ATNF's remarkable collection of historical images assembled by professional photographers employed by RP from the very early days of Australian radio astronomy. But the photographic collection included more than just radio astronomy, for at the end of WWII RP also experimented with electronic computers, commercial radar systems, vacuum physics, police radars, as well as rain and cloud physics that were to become the Division's other major research forte. My first task was to separate the non-radio astronomy and radio astronomy images, and then catalogue the latter. It was then that the idea emerged to use this incomparable visual record as the basis of a book on the RP field station era. This made good sense as Bruce Slee (by then retired, but continuing his work as an ATNF Research Associate) and I had already started writing papers on the different RP field stations, and some of their unique radio telescopes (such as the Dover Heights 'hole-in-the-ground' antenna). And soon we would start to co-supervise PhD students Harry Wendt and Ron Stewart who respectively would document the main achievements of the Potts Hill and Murraybank, and the Penrith and Dapto, RP field stations.

I then discussed the idea of a copiously-illustrated scholarly book about the RP field stations with Springer, who agreed to be the publisher, but on the understanding that the ATNF would prepare a camera-ready version of the manuscript. I also invited Woody Sullivan to join me as a co-author, so that I could access the files on RP radio astronomy that he had accumulated when researching his classic, *Cosmic Noise – A History of Early Radio Astronomy* (Cambridge University Press, 2009). He agreed, and in 2004 I spent two months in the Astronomy Department at the University of Washington, Seattle, working my way through Woody's incomparable collection (which has since been transferred to the National Radio Astronomy Observatory Archives in Charlottesville, Virginia). Once back in Sydney I commenced writing, and by 2005 I had completed most of the text of the book, selected images for the first four of the five chapters, and prepared captions for them.

Meanwhile, the scheduled fifth and final chapter in the book, about the post-1960 era in Australian radio astronomy, was to be written by the ATNF's Jessica Chapman, as the third co-author of the book, and she also was responsible for preparing the camera-ready manuscript.

Then came a major event that threatened to halt this project altogether or at very least substantially delay publication: Ron Ekers was awarded an inaugural and prestigious Federation Fellowship and stepped down as Director of the ATNF so that he could concentrate on full-time research. Unfortunately, Ron's successor had no sympathy for historical research at the ATNF and suddenly I was out of a job. Meanwhile, Jessica found it increasingly difficult to allocate time for preparation of the camera-ready manuscript of the book, let alone to research and write up Chapter 5. Eventually, Springer's policy also changed, and they were no longer willing to accept camera-ready manuscripts of new books; all production was now to be done in-house. This led to an impasse, and several years passed without any resolution.

Eventually, Jessica left the collaboration, and Woody Sullivan and I signed a new contract with Springer, but there was still a major problem: gaining access to many of the ATNF images required for the book. And Chapter 5 still had to be researched and written. Meanwhile, I was busy writing other books for Springer, and also teaching a History of Astronomy course for the on-line Master of Astronomy degree at James Cook University in Townsville, Queensland (which is where I moved after leaving the ATNF), and supervising further PhD students. One of these students, Peter Robertson, was researching John Bolton's major contribution to international radio astronomy, including his pioneering work with Gordon Stanley and Bruce Slee at the Dover Heights field station in the late 1940s and early 1950s. Peter had also researched the RP field stations when he prepared his book *Beyond Southern Skies – Radio Astronomy and the Parkes Telescope* (Cambridge University Press, 1992), the standard work on the history of this iconic Australian radio telescope. Peter and I agreed that after he submitted his PhD thesis and after his Bolton book was published he would join with Woody and me and complete the long-delayed field stations book. Springer was very relieved to hear this news, even if it meant yet another contract.

Once Peter began updating the original manuscript it soon became obvious that we all had grossly underestimated what this task would entail. A great deal of additional historical research had been published on Australian radio astronomy since 2005 – indeed, it is probably true that this topic has received more attention from historians of science than any other branch of Australian science. All this new material had to be absorbed and assimilated into the text, and the new references added. Peter also agreed to write a detailed version of Chapter 5, an overview of the development of Australian radio astronomy since 1960. The Parkes Telescope, the Molonglo Cross and its evolutionary derivatives, the Fleurs Synthesis Telescope and the Australia Telescope have been discussed in Chapter 5, along with the Square Kilometre Array and the two Australian 'pathfinders'. One outcome of having a Chapter 5 much larger than originally intended was that the book no longer relied almost entirely on the collection of ATNF historical photographs, as we were able to include a much wider range of images. However, a significant setback occurred when the ATNF collection – known as the CSIRO Radio Astronomy Image Archive (CRAIA) – was shut down for almost two years while the database and software underwent a major upgrade, which further delayed completion of the manuscript. Online access to CRAIA was finally restored in September 2019, allowing us at long last to bring this 15-year project to a successful end – much to the great relief of Springer, not to mention all three authors.

This long and difficult project would never have been completed but for the assistance of many people. For their support and encouragement throughout we owe special thanks to Phil Edwards, Ron Ekers, Dick Manchester and Bruce Slee, and to the staff at Springer, especially Maury Solomon and Hannah Kaufman, for making it possible to bring this project to fruition.

For their valued comments and insights on Chapter 5, we thank Bob Frater, Dave Jauncey, Ken Kellermann, Dick Manchester and Richard Schilizzi.

Just over half of the nearly 300 images in this book have been drawn from CRAIA, hosted by the ATNF in the Sydney suburb of Marsfield. For her advice and support we are especially grateful to Jessica Chapman, who has managed the CRAIA project for over two decades and done much of the technical development. We are also grateful to Barnaby Norris who digitised the great majority of CRAIA images and helped set up the original web version of CRAIA; to Lawrence Toomey who sent us high resolution versions of the CRAIA images in this book; and to Vicki Drazenovic who, together with Jessica, did the layout for the first two chapters in the original version of this book (before Springer changed its policy on camera-ready copy).

We would particularly like to thank the following for providing us with one or more photographs reproduced in this book: Letty Bolton, Ellen Bouton, Alex Cherny, Joe Diamond, Martin George, Mary Harris, Lisa Harvey-Smith, Bob Hewitt, Dick Hunstead, Ken Kellermann, Ros Madden, Chris Phillips, Jim Roberts, Bruce Slee, Stephen and Teresa Stanley, Govind Swarup, Harry Wendt and Pete Wheeler. A special thanks to Geoff Kelly who improved the quality of a significant number of images with Photoshop.

We are especially grateful to CSIRO Space and Astronomy for providing a generous publication grant, which has enabled our work to be published in the Springer series of Open Access books.

As this book goes to press, we celebrate the 75th anniversary of the birth of Australian radio astronomy. In October 1945, Joe Pawsey, Lindsay McCready and Ruby Payne-Scott made the first successful radio observations of the Sun from the northern beach suburb of Collaroy in Sydney. We salute them, and all those pioneers who followed and contributed to the remarkable story of Australian radio astronomy. Their fascinating achievements are scattered throughout this book.

Finally, we wish to dedicate our book to Bruce Slee, whose perseverance and achievements have been an inspiration to all of us.

Chiang Mai, Thailand — Wayne Orchiston
Melbourne, Australia — Peter Robertson
Seattle, USA — Woodruff T. Sullivan III

Contents

Chapter 1
From Radar to Radio Astronomy

Today's astronomers study the sky at a wide range of wavelengths, spread across the electromagnetic spectrum, from radio through microwave, infrared, the optical range, the ultraviolet, X-rays and gamma rays (Fig. 1.1). They also use cosmic rays and neutrinos, and the newest field is gravitational wave astronomy. Some of these types of radiation can be observed from the Earth's surface, others rely on space telescopes. Some are comparatively recent innovations, while optical astronomy – in various guises – dates back many millennia.

In radio astronomy we study the radio waves emitted by the Sun, planets and comets of our Solar System, and the stars, dust and gas in our Galaxy and in other galaxies and clusters of galaxies. While the concept of extraterrestrial radio emission dates back to the 1890s, radio astronomy as a new and exciting branch of astronomy only had its origins in the early 1930s when the American physicist Karl Jansky (1905–1950) detected 20 MHz radio emission from the Galaxy (Fig. 1.2; see Sullivan, 2009 for a comprehensive and definitive history of radio astronomy through to 1953). Jansky was a remarkable man (see Biobox 1.1), and it is unfortunate that his employer, the Bell Telephone Laboratories, did not let him pursue these early ground-breaking discoveries further. Instead it was left to Grote Reber (1911–2002; Biobox 1.2) to take radio astronomy to the next level, and to interest optical astronomers in the research potential of this new field. Radio engineering was Reber's profession *and* hobby, and after trying unsuccessfully to obtain a position with Jansky and to interest some leading optical astronomers in 'cosmic static', he realised "Nobody was going to do anything. So … maybe I should do something. So I consulted with myself and decided to build a dish!" (Kellermann, 2005: 49).

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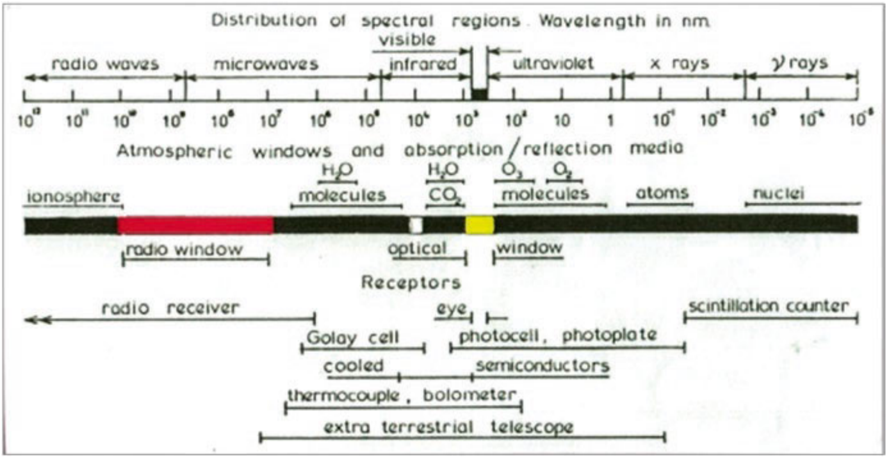

Fig. 1.1 The electromagnetic spectrum, showing the span of the radio window (courtesy: Orchiston collection)

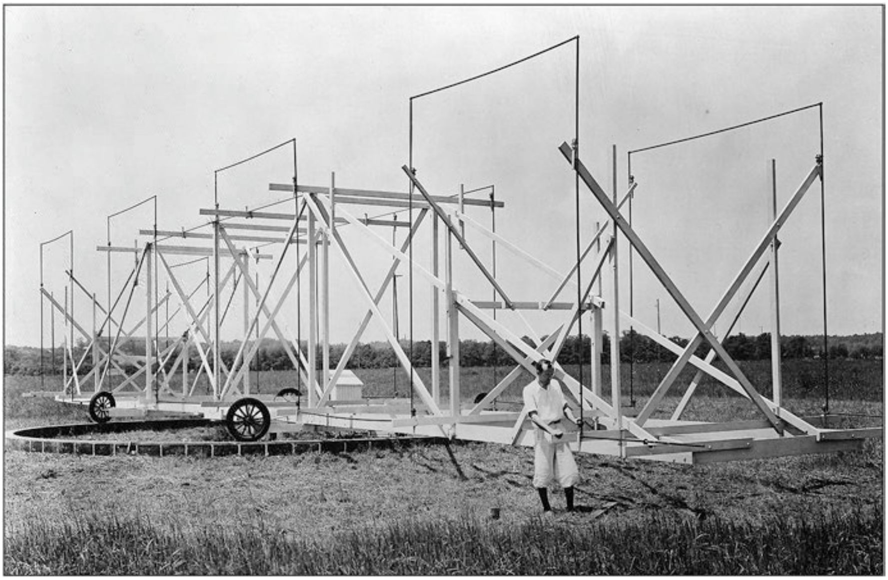

Fig. 1.2 Karl Jansky used the 20.5 MHz 'merry-go-round' antenna at Holmdel, New Jersey, for his studies of extraterrestrial radio emission (courtesy: US National Radio Astronomy Observatory)

In his spare time he built a 9.75 m (32 ft) diameter parabolic dish in the property next door to his mother's home in Wheaton, Illinois (Fig. 1.5). This was in 1937, and although "Neighbours speculated about the purpose of the unfamiliar-looking structure … Reber's mother found it a convenient place to hang her washing!" (Kellermann, 2005: 49). After experimenting with different receivers, he eventually

Biobox 1.1: Karl Jansky

Karl Guthe Jansky (Fig. 1.3) was born in Oklahoma on 23 October 1905, and graduated with a BSc in physics from the University of Wisconsin in 1927. After a year of post-graduate study, he joined the Bell Telephone Laboratories (BTL), but because he was diagnosed with a kidney disease (Bright's disease) was posted to a rural radio field station at Cliffwood, New Jersey, rather than the main research laboratory in New York. He began researching static associated with shortwave radio transmissions in August 1928, and in 1930 the group transferred to nearby Holmdel. It was there that he built the 'merry-go-round' antenna. In an August 1931 report "… we find what in retrospect appears to be the first recognition of a new, weak component of static." (Sullivan, 1984b: 10). This weak emission, recorded at 20.5 MHz, was researched during 1932 and first mentioned in a research paper by Jansky published that year in the *Proceedings of the Institute of Radio Engineers*.

Jansky continued his investigations on an intermittent basis during 1931 and through 1932 as the Great Depression altered the BTL's research priorities, but by December 1932 he was in a position to conclude that the mysterious 'static' was extraterrestrial in origin. The concept of radio astronomy was born. In 1933 Karl spoke about his research at meetings in Washington and Chicago on 27 April and 27 June respectively. He also published research papers on this work in *Nature* and *Proc. IRE.* Following the Washington meeting, the BTL issued a press release, and on 5 May the front page of the *New York Times* devoted an entire column to the "New radio waves traced to the center of the Milky Way …". Jansky became an instant international celebrity! By August 1933 Jansky was convinced that the static originated from the entire Milky Way, and not just from the central region. The following month Jansky targeted his findings at an astronomical audience through an article in the magazine *Popular Astronomy*, but this was also the time that Jansky turned to other static-related research that was more appropriate to BTL's practical needs.

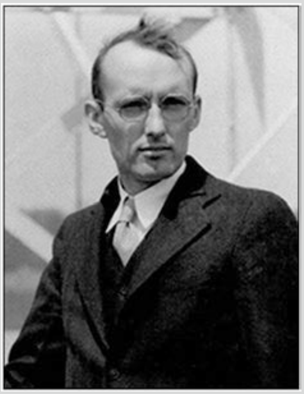

Fig. 1.3 Karl Jansky (1905–1950) was the founding father of radio astronomy (courtesy: US National Radio Astronomy Observatory)

(continued)

Biobox 1.1 (continued)

Only in 1935 did he briefly return to his ‘star noise’ research, and publish two final papers in *Proc. IRE* in 1935 and 1937. This marked the end of Jansky’s exciting foray into the field that would ultimately be known as radio astronomy, but within months of submitting his 1937 paper the cause would be taken up by another pioneer, Grote Reber, who began building a 9.75 m diameter parabolic radio telescope at Wheaton, Illinois. For his part, Jansky “… continued on the same theme of understanding and minimising the sources of noise in radio communications, whether they were internal to the electronics or external to the antenna, manmade or natural.” (Sullivan, 1984b: 24), and his merry-go-round was used as a mount for a variety of different antennas (see also Sullivan, 1984c).

With the passage of the years, Jansky’s lifelong kidney ailment led to blood pressure problems, and he eventually died of a stroke in February 1950; he was just 44 years of age. While he never received any official honours or rewards during his short lifetime, other than being made a Fellow of the Institute of Radio Engineers, Karl will always be warmly remembered as the founder of radio astronomy:

> There can be no doubt that he is the father of radio astronomy – but (shifting metaphors) only in the sense of finding and sowing the seed, not in raising the crop. Through a combination of circumstances, his discovery fell on stony ground and was not to yield fruit until the technical demands of a war created a new generation of men and equipment. (Sullivan, 1984b: 35–36).

Biobox 1.2: Grote Reber

Grote Reber (Fig. 1.4) was born in Chicago on 22 December 1911, and obtained a degree in Electrical Engineering from the Armour Institute of Technology (now the Illinois Institute of Technology). From his teens, he was an avid radio ham, and after reading about Jansky’s work he decided to conduct research in this new field and in 1937 he built a 9.75 m parabolic transit dish. Subsequently, he published a succession of research papers, mostly on ‘Cosmic static’. It is fair to say that initially his work was viewed with skepticism by most optical astronomers (see Reber, 1984 for a personal account).

Soon after WWII, Reber accepted a position at the Central Radio Propagation Laboratory of the National Bureau of Standards and sold his dish and associated instrumentation to his employer on the expectation of building a 23–30 m dish for research. This did not happen, and he quickly became disillusioned and decided to move to Hawaii where he could conduct independent research in radio astronomy. There he erected a sea interferometer on the summit of Mt Haleakala but it produced disappointing results. In November 1954 he moved to Tasmania, and over the next half-century built a succession

(continued)

Fig. 1.4 Grote Reber (1911–2002) laid the foundations of radio astronomy during the late 1930s and early 1940s (courtesy: US National Radio Astronomy Observatory)

of very low frequency arrays and published a series of paper on his research (George et al., 2015b, 2015c, 2017). Whilst widely regarded as one of the 'fathers of radio astronomy', Reber unfortunately promoted cosmological views that were at odds with most other astronomers. He also had little respect for the standard refereeing process used by scientific journals, and was openly critical of politicians, the National Academy of Science and the National Science Foundation in the USA and the work done at the US National Radio Astronomy Observatory. He was able to adopt this stance and maintain his independent status because he received strong financial support over several decades from the Research Foundation.

Although Reber operated outside the 'mainstream astronomical community', he was awarded the Bruce Medal by the Astronomical Society of the Pacific, the Elliot Cresson Medal of the Franklin Institute, and the Russell Lectureship of the American Astronomical Society. He received an honorary DSc degree from Ohio State University, and in 1999 was named 'Man of the Millennium' by the Illinois Institute of Technology. A man of diverse interests, he also conducted research and published on radio-circuitry, ionospheric physics, cosmic rays, meteorology, botany and archaeology. Grote was also deeply concerned about environmental, social and political issues. In Bothwell, Tasmania, he built his modest energy-efficient home, and a battery-powered car. After a long and eventful life, he died in Bothwell in December 2002. For further details of his remarkable life, see Robertson (1986) and Kellermann (2005).

detected Jansky's 'cosmic static' in 1939, and went on to observe the sky at 160 and 408 MHz and to produce the first high-resolution contour maps of Galactic radio noise. Reber wrote papers on his 'cosmic static' and they were quickly published in the *Proceedings of the Institute of Radio Engineers*, but it was a different story when

Fig. 1.5 Grote Reber's home-made 9.75-metre parabolic antenna mystified his neighbours at Wheaton, Illinois (courtesy: US National Radio Astronomy Observatory)

he tried to share his exciting new finds with astronomers. When he submitted a paper to the prestigious *Astrophysical Journal* it caused a flurry of excitement and curiosity. Who was this fellow without an astronomy degree or an observatory affiliation, what equipment did he use for these strange observations, and what did they mean? Several delegations of astronomers, mainly from the famous Yerkes Observatory, went to Wheaton to meet Reber and see his equipment for themselves. They seemed suitably impressed, and the editor Otto Struve eventually decided to accept Reber's paper, but only after some editorial censoring. Reber was less than impressed with these delays and changes and later stated that while Struve may not have rejected the paper,

> He merely sat on it until it got mouldy. I got tired of waiting, so I sent some other material to the Proceedings of the IRE. It was published promptly … During the early days of radio astronomy, the astronomy community had a poor [publication] track record. The engineering fraternity did much better. (Kellermann, 2005: 52).

After making pioneering Milky Way observations, in 1943 Reber went on to detect radio emission from the Sun. Jansky and Reber, joined by essentially no one else, can rightly be considered the 'founding fathers' of radio astronomy.

But if radio astronomy was born during the 1930s, it only began to grow during the late 1940s, mainly because of independent discoveries of solar radio emission in

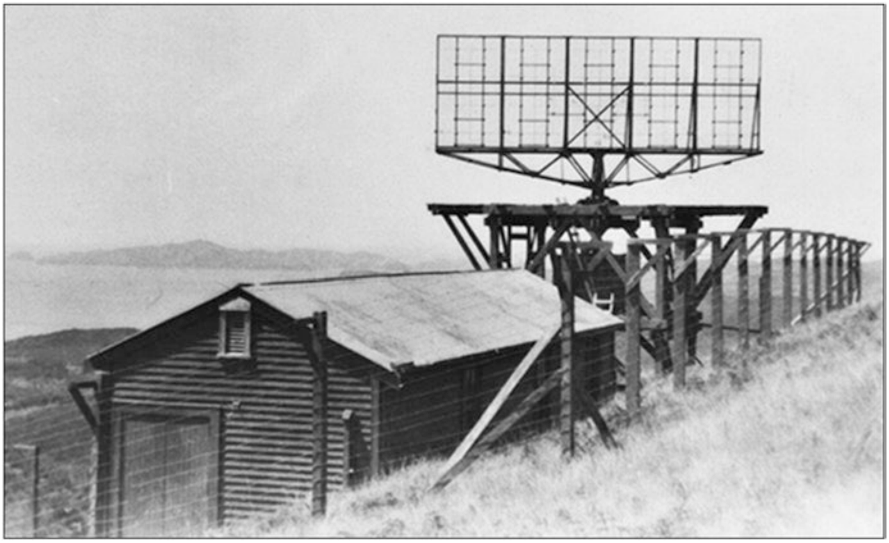

Fig. 1.6 The RNZAF Wainui radar station near the northern-most tip of the North Island of New Zealand, showing the 200 MHz antenna used for solar observations immediately after sunrise (courtesy: Orchiston collection)

England, the USA, Australia and New Zealand during World War II. Most of these involved radar antennas, and since the 'solar noise' was initially thought to be some form of enemy jamming technique these discoveries were treated as 'secret' or 'top secret'. Strangely, it was the New Zealand discoveries that had the greatest impact in Australia, and led directly to the launch of an ambitious radio astronomy research program by the Radiophysics Laboratory in Sydney (which we shall often refer to simply as RP). The New Zealand solar research was the responsibility of Dr Elizabeth Alexander (1908–1958), Head of the Operational Research Section of the Radio Development Laboratory. Between March and December of 1945 she arranged for solar monitoring to be carried out at a number of different Air Force radar stations (Fig. 1.6). British-born Alexander (see Biobox 3.1 in Chapter 3)

> … prepared a number of reports on this work, and in early 1946 she published a short paper in the newly-launched journal, *Radio & Electronics*. A geologist by training, Elizabeth Alexander happened to be in the right place at the right time, and unwittingly became the first woman in the world to work in the field that would later become known as radio astronomy. (Orchiston, 2005b: 71).

In Australia, Radiophysics had been established at the beginning of WWII in order to develop radar technology for Australian sites and the Pacific theatre (Fig. 1.7). Radiophysics was one of a number of divisions that made up the Council for Scientific and Industrial Research, Australia's leading research organisation. In 1949 CSIR was reconstituted and renamed the Commonwealth Scientific and Industrial Research Organisation (CSIRO) [see Schedvin (1987) and Collis (2002) for official histories of CSIR and CSIRO respectively].

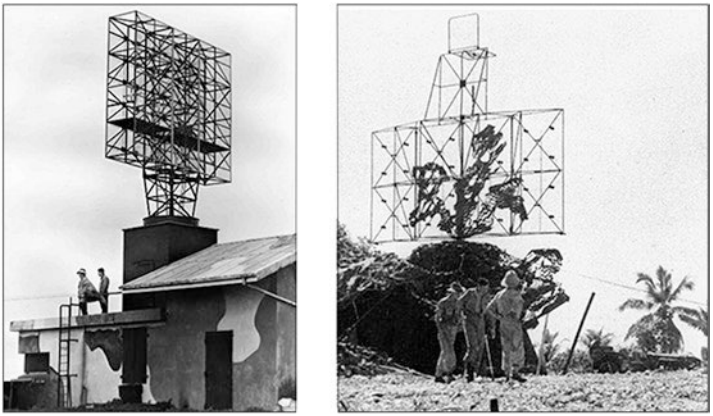

Fig. 1.7 (left) The experimental radar antenna at the Dover Heights field station in Sydney. The antenna was used for the detection of ships along the Australian coast, but then a new version was hurriedly developed for air warning following the Japanese attack on Pearl Harbor. (right) The light-weight/air-warning (LW/AW) portable radar developed by the Radiophysics Lab especially for tropical conditions in the Pacific. The equipment could be airlifted to forward areas and then rapidly assembled. This unit was installed on Tumleo Island near the north coast of New Guinea [courtesy: CSIRO Radio Astronomy Image Archive (henceforth CRAIA)]

In mid-1945 one of Elizabeth Alexander's confidential reports reached the RP Chief, Dr E.G. ('Taffy') Bowen (1911–1991; Biobox 1.3), and his deputy, Dr Joe Pawsey (1908–1962). The New Zealand work fascinated them, and they decided to try and repeat it using a Royal Australian Air Force radar antenna at Collaroy, in suburban Sydney. Pawsey's initial success profoundly influenced the direction of research to be undertaken by Radiophysics in the immediate post-war years, for the Laboratory was under considerable pressure to reinvent itself and find a range of peace-time research projects – any surviving projects with military applications had to be transferred to the defense services.

Biobox 1.3: Taffy Bowen

Edward George Bowen (Fig. 1.8) was born near Swansea in January 1911 and later in life was proudly known by his Welsh nickname of 'Taffy'. As a boy he took a keen interest in radio technology, which sowed the seeds for his future career. He studied physics at the University College of Swansea and in 1934 he was awarded a PhD at King's College London, under the supervision of Edward Appleton. In 1935 Bowen joined Robert Watson Watt's group at the Bawdsey Manor research station working on the highly secret technique of radio detection finding (later known as radar). Taffy was given the responsibility of building the first airborne radar system, which was successfully tested in September 1937. Bowen's other major contribution to the war effort was as a member of the Tizard mission to the United States in 1940 to inform the Americans about recent British

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Biobox 1.3 (continued)

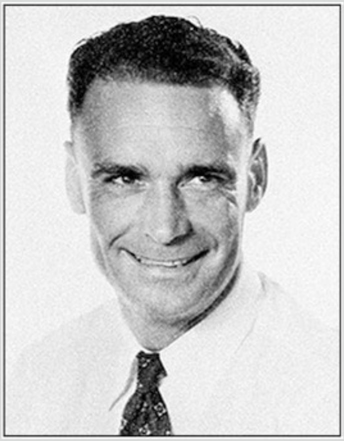

Fig. 1.8 Dr Edward ('Taffy') Bowen (1911–1991) was Chief of the Radiophysics Lab from 1946 to 1971 (courtesy: CRAIA)

technical advances, including radar. He spent most of the war years shuttling between England and the Massachusetts Institute of Technology which was the centre of US radar research and development (Bowen, 1987).

In late 1943 Taffy accepted an offer to become Assistant Chief of the Radiophysics Lab in Sydney and, two years later, he was elevated to the position of Chief. At the end of the war, the Lab had a group of highly talented staff looking for new research directions. Two major peacetime programs emerged: cloud and rain physics under Bowen's direction, and radio astronomy led by Joe Pawsey. Taffy was a pioneer of cloud seeding experiments in Australia, although his controversial ideas about the influence of meteoric dust on rainfall were mostly discredited. Bowen believed that future advances in radio astronomy would require large and expensive aerial systems and he became the driving force behind the planning and construction of the Parkes Radio Telescope (see Chapter 5). Opened in 1961, the iconic Parkes dish has been at the forefront of astronomical research for over sixty years. The dish was also involved in the series of Apollo missions to the Moon over the period 1969–72. Bowen also made a significant contribution to the establishment of the Anglo-Australian Telescope at Siding Spring in NSW as the inaugural chair of the AAT Board.

In 1972 he was appointed scientific counsellor at the Australian Embassy in Washington, DC, where he spent the remainder of his career. Taffy received a number of prestigious awards and honours over his distinguished career, including the Medal of Freedom USA (1947) for his contributions to radar research and a Commander of the Order of the British Empire (CBE, 1962) for his services to Australian science. In 1975 he was elected a Fellow of the Royal Society of London. For more on Taffy Bowen see Hanbury Brown et al. (1992) and Bhathal (2014).

Fig. 1.9 Testing a navigational radar system housed under the 'dome' on the nose of the aircraft (courtesy: CRAIA)

Fig. 1.10 A mobile traffic radar system was developed by the Radiophysics Lab for the New South Wales Police Force. RP scientist Harry Minnett (left) explains the system to the NSW Minister for Police (courtesy: CRAIA)

Various fields were investigated in the ten years following WWII, including cloud physics and rainmaking, navigational aids for civilian aircraft and ships (Fig. 1.9), a mobile traffic radar system for the NSW police force (Fig. 1.10), and radio astronomy (or, more properly, 'solar noise' and 'cosmic noise', to use the terminology of the day) (see Bowen, 1988; Sullivan, 2005). A vacuum physics laboratory was set up, work was carried out on transistors, and plans were made for a linear accelerator for nuclear physics. Australia's first computer was constructed at this time, known as CSIRAC – the CSIRO Automatic Computer (Fig. 1.11). CSIRAC was put to work on a number of RP research programs, but surprisingly had little impact on the radio astronomy program. Most of the tedious calculations required to reduce observational data were made by the radio astronomers themselves or by other RP staff (mostly women). Apart from radio astronomy, the aim of the RP research work was to come up with technological developments that would assist the Australian economy, and the Division's exploits in rainmaking (Fig. 1.12) certainly had the potential to do this if they proved successful.

From the start, the RP radio astronomy program was under the capable leadership of Joe Pawsey (Biobox 1.4). Australian by birth, but Cambridge-trained,

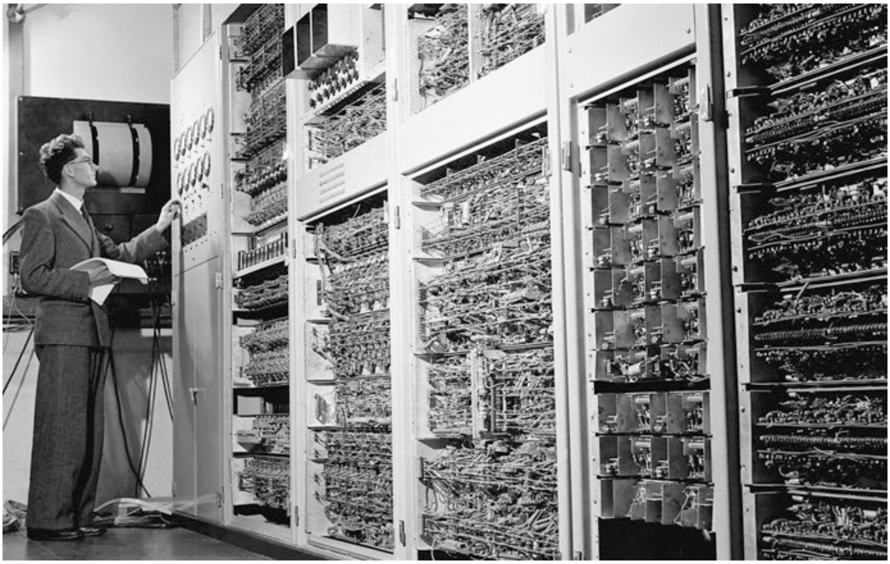

Fig. 1.11 Trevor Pearcey and CSIRAC, the first (and last) computer to be wholly designed and built in Australia. CSIRAC is now on display at the ScienceWorks Museum in Melbourne and is the oldest first-generation computer still in existence (courtesy: CRAIA)

Fig. 1.12 During the 1950s and 1960s, apart from radio astronomy, the other major research area at Radiophysics was rainmaking. Silver iodide burners were attached to aircraft and used to seed clouds in selected areas of eastern Australia. Military aircraft were used for the trials because silver iodide is highly inflammable and too dangerous to use on commercial aircraft (courtesy: CRAIA)