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Gordon James Stanley and the Early Development of Radio Astronomy in Australia and the United States

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Abstract: Following the end of the Second World War, the CSIRO Radiophysics Laboratory applied the expertise and surplus radar equipment acquired during the war to problems of astronomy. Gordon Stanley was among the first group of scientists and engineers to work in the exciting new field of radio astronomy. Like many of his contemporaries, he had a strong background in radio and electronics but none in astronomy. At the Radiophysics Laboratory, and later at Caltech, Stanley developed innovative new radio telescopes and sophisticated instrumentation which resulted in important new discoveries that changed, in a fundamental way, our understanding of the Universe. He was one of those who played a key role in the early development of radio astronomy both in Australia and the United States.

Keywords: Gordon Stanley — radio astronomy — radio stars — Galactic Centre

Introduction

Radio astronomy had its origins in the 1930s, through the pioneering exploits of Karl Jansky and Grote Reber (see Kellermann & Sheets 1983; Sullivan 1984), but it only blossomed in the late 1940s and early 1950s, largely as a result of technological developments associated with radar during the Second World War. By 1950, Britain and Australia had emerged as the forefront nations in this new branch of astronomy (Sullivan 1988), and although there were short-lived teams based at Mount Stromlo Observatory and at the University of Western Australia, most of the Australian initiatives were associated with the CSIRO's Division of Radiophysics (henceforth RP) in Sydney. Gordon Stanley was one of these early RP pioneers, and his skills in radio technology helped open a branch of astronomy, one which was subsequently associated with a series of remarkable discoveries, including radio galaxies, quasars, pulsars, gravitational lensing, interstellar masers, extra-solar planets, and the cosmic microwave background.

Between 1945 and 1961, RP maintained several different field stations at or near Sydney (Figure A1, see the Accessory Materials), where small groups of scientists and engineers developed new instrumentation which they used in a multi-faceted assault on radio astronomy. Those of us (B.S. and W.O.) fortunate to have been around during the field station era look back with a degree of nostalgia on those halcyon days, beautifully described by one of our colleagues, 'Chris' Christiansen (1984):

> 'The field work had a pioneering appearance. Each morning people set off in open trucks [by the 1960s Commonwealth cars] to the field stations where their equipment, mainly salvaged and modified from radar installations, had been installed in ex-army and navy huts. At the field stations the atmosphere was completely informal and egalitarian, with dirty jobs shared by all. Thermionic valves were in frequent need of replacement and old and well-used co-axial connectors were a constant source of trouble. All receivers suffered from drifts in gain, and 'system-noise' of hundreds or thousands of degrees represented the state of the art. During this period there was no place for observers who were incapable of repairing and maintaining the equipment.'

One of the most prominent field stations was Dover Heights (site number 2 in Figure A1), where the trio of Stanley, John Bolton, and Bruce Slee soon established international reputations through their studies of the enigmatic 'radio stars'. This biographical paper is about Stanley's research accomplishments at Dover Heights, and his later involvement with the development of radio astronomy in the USA following his move to the California Institute of Technology in 1955.

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Gordon James Stanley: A Biographical Sketch

Gordon James Stanley (Figure 1) was born in Cambridge, New Zealand, on 1921 July 1. His father, Percy, suffered from tuberculosis and needed to live in a warmer, dryer climate, so the family moved to Sydney, Australia, when Gordon was just six year old. There he attended Blue Street Junior High School in North Sydney, doing well in Latin, physics, and mathematics, not so well in French, and intensely disliking chemistry. At the urging of his father, he left school at the age of 14 to begin work as an apprentice at EMMCO (Electrical Meter and Manufacturing Co.), a large manufacturer of electrical equipment. Later the company changed its name to EMAIL (Electrical Meter and Allied Industries).

Stanley (undated notes) later recalled that, 'EMAIL had an almost unbelievable range of products, but as its name suggests, its basic product was the electrical power consumption meter. It was a major manufacturer of refrigerators, washing machines, and a minor manufacturer of radios, the later featuring the first remote control on the market.' Young Stanley worked in all of the departments, where he received the rigorous training that was to serve him so well later in life. He worked in turn in the very large machine shop, the coil winding shop, the foundry, a pattern making shop, and a sheet metal shop with extensive plating facilities. In 1937, EMAIL acquired a firm called 'Palmer Switchgear' which manufactured a wide range of power station equipment, including a 11000 V, 1000 A circuit breaker and a 5000 V, 2000 A switch. Stanley then specialised in power station equipment, and was involved in trouble shooting what he described as '... the spectacular failures that sometimes occur in high voltage switches and buses' (personal communication to K.I.K., 1994). While working at EMAIL, he continued his studies at Sydney Technical College, from which the University of New South Wales later evolved. Splitting his time between his studies and work, he earned his high school diploma and then began a Diploma in Engineering. As he later recalled, the valuable hands-on experience gave him '... a head start over an engineer who experienced college before working in the real world' (ibid.).

Figure 1 Gordon James Stanley, 1921–2001. The photograph was taken during the 1950s (courtesy: Joyce Hales).

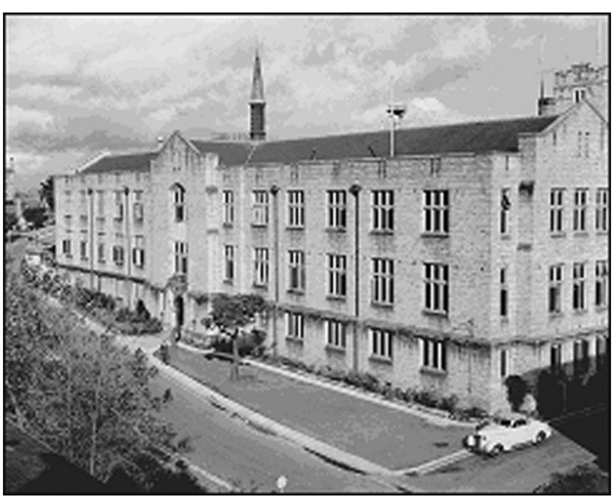

Figure 2 The Radiophysics Laboratory, headquarters of Australian radar developments during the Second World War, was in the grounds of the University of Sydney (ATNF Historic Photographic Archive: 2941–9).

Like many young men of the time, the Second World War interrupted Stanley's career, and he joined the army as an infantry private. But, after six months he was placed on reserve and returned to EMAIL where he worked twelve-hour shifts manufacturing parts for shell fuses and switching gear. He applied for pilot training, but was rejected because of colour blindness.

In 1943, Stanley was ordered by the wartime manpower authority to take a position at the CSIRO's Radiophysics Laboratory in Sydney (Figure 2), and in 1944 January he began work there as a journeyman tradesperson (Stanley 1986). Unlike EMAIL, where the staff had a wide range of ages, educational backgrounds, and social classes, he described RP as '... more like a country club, despite the Federal Guards in the lobby' (personal communication, Helen Stanley to K.I.K., 2003). In 1950, at the age of 29 and at the height of his Radiophysics career, he married Helen and they subsequently had three children, Teresa, Luise, and Stephen.

The Radiophysics Years

After experiencing the commercial world first-hand, Stanley found RP a very different work environment. Here were people of similar ages with university backgrounds, and stimulating lectures to attend, not only on work-related subjects but also on politics, the humanities, and sport. The highly developed (and classified) work at the RP Laboratory offered him a new opportunity for increasing his skills in microwave and valve technology, and the newly emerging field of information technology. In particular, he later recalled (Stanley 1994) the help and support he received from Garth Dewsnap and Ted McCarthy, both of whom left RP at the end of the war.

Early in 1945, Stanley was promoted to Technical Assistant, and transferred to 'Group D' under Lindsay McCready. He fondly remembers that '... towards the end

Figure 3 John Bolton (left), Gordon Stanley (centre), and Joe Pawsey (right) at the RP Laboratory in early 1954.

Figure 4 The War-era blockhouse, with 100 (left) and 60 MHz (right) twin Yagi antennas mounted on the roof. The 200 MHz 4-Yagi antenna which was located on the seaward right-hand corner of the blockhouse is not readily visible in this photograph (ATNF Historic Photographic Archive: 1031–3).

of 1945 . . . I designed and produced my first antenna system (a Yagi), with receiver. We used it to observe the Sun from North Head' (Stanley 1986). On 1945 December 31 he received his Diploma in Engineering, and the following month was appointed a Technical Officer. Later that year, he and McCready developed a 4-Yagi 200 MHz system and installed this at Mt. Stromlo Observatory, where it was used successfully by Clabon Allen to study solar and Galactic radio emission (see Allen 1947; Allen & Gum 1950). So by the end of 1946, Stanley had expertise in observing and in the design and construction of antennas and receivers.

Stanley first began working with John Bolton (Figure 3) in early 1947 while building radio equipment to observe a total solar eclipse in Brazil (see Bolton 1982). It was at this stage that Bolton and Stanley discussed the possibility of resuming a search for extra-solar radio sources using the sea interferometer technique, which Bolton and Slee had begun at Dover Heights with inadequate sensitivity in 1946 November (see Slee 1994). When the expedition to Brazil was cancelled, Pawsey suggested that Stanley and Bolton resume solar observations with the improved 60, 100, and 200 MHz receivers and 2- and 4-Yagi antennas, setting them up on a large concrete blockhouse at Dover Heights (see Figure 4) on the cliff edge some 79 m above the Tasman Sea and 5 km south of the entrance to Sydney Harbor. They had Pawsey's blessing to search for cosmic sources if the Sun happened to be inactive. Stanley was responsible for designing and building the improved receivers and the associated power supplies and recording equipment.

Stanley, Bolton, and Ruby Payne-Scott used this equipment during a period of high solar activity in 1947 March–April to record an unusually intense radio burst, which drifted slowly in frequency from 200 to 60 MHz (Payne-Scott, Yabsley, & Bolton 1947); this was later recognised as the first time an important class of solar radio emission, the Type II burst, had been recorded (Figure 5), and the discovery played a crucial role in the subsequent development of solar radio astronomy. Both Stanley and Bolton found that Payne-Scott could be exasperating, but they certainly recognised her scientific ability. Payne-Scott

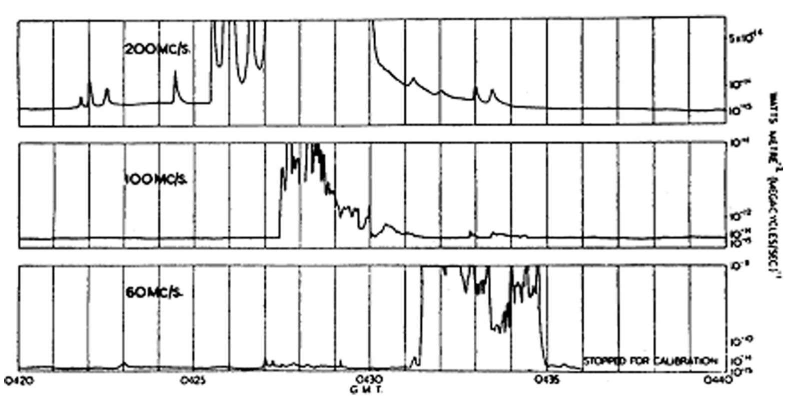

Figure 5 The solar outburst recorded on 1947 March 8 recorded at three different frequencies. Note the different arrival times of the signals (ATNF Historic Photographic Archive: 1166–4).

was still at Dover Heights when Slee (Figure A2) arrived to join the team in 1947 September, and discovered that Stanley had painted 'Men Only' on the toilet door. Later Stanley (1997) was to reminisce that: 'She was part of my early education on women's issues, and despite early insensitivities on my part, I grew to have a great respect and liking for her.'

The lack of solar activity in 1947 May–June prompted Bolton and Stanley to use the 100 MHz system as a sea interferometer to search for fringes from the hypothetical source in Cygnus first suggested by the intensity variations reported by Hey, Parsons, & Phillips (1946). The sea interferometer functions by exploiting the interference between the radio waves received directly by an antenna located on a cliff-top overlooking the sea and those radio waves reflected off the sea. As the Earth rotates, the differential path length between the two signals changes, causing successive constructive and destructive interference. This effect was first noticed during the Second World War by radar operators. The effective resolution of a sea interferometer is equivalent to that of a two-element interferometer with a spacing equal to twice the height of the single cliff antenna. Bolton and Stanley soon detected interference fringes with their novel interferometer, and a typical record, reproduced in Figure 6, showed that the source was less than 8 arcminutes in diameter. Subsequently, daily rising patterns with the antenna pointed in various north-east directions yielded a very approximate position. Over the next two to three months Cygnus A was also detected with the 60 and 200 MHz receivers and a rough radio spectrum (subsequently found to be inaccurate) was plotted. This ground-breaking discovery was reported by Bolton & Stanley (1948a, 1948b). From late 1947 to early 1948, Bolton, Stanley, and Slee conducted what was probably the world's first spaced-antenna experiment, with aerials at Dover Heights and Long Reef, $\sim$20 km away on the northern side of Sydney Harbour, in order to measure the degree of correlation between the very obvious intensity variations from Cygnus A at the two sites. They found there was a high correlation, and if the variations were due to a diffraction pattern sweeping across the Earth this indicated the scale of the electron density turbulence was greater than 2 km (the length of the projected base line).

The pressure was now on to find more radio sources, which led to a survey with the 100 MHz sea interferometer. Starting in 1947 November, the observational work involved spending several nights on each of about fifteen azimuth settings separated by $\sim$10°. If a weak interference pattern was suspected, the azimuthal position was checked several times before the existence of a source was accepted (the intensities of these new sources were about five times below that of Cygnus A). The first of the survey sources (Taurus A) was found on November 6 (see Figure 7), followed over the next few months by Centaurus A and Virgo A. The positions found for these sources were too inaccurate to attempt optical identifications (see Bolton & Stanley 1949), although Bolton, Slee, and Stanley knew they were outside the solar system and, if extragalactic, must have had almost unbelievably high radio luminosities.

Their first priority was to obtain more accurate positions for these sources, and a much higher cliff was sought which would allow observations of the sources when both rising and setting. Bolton and Stanley eventually selected two sites in the North Island of New Zealand, with coastal cliffs $\sim$300 m above sea level (see Orchiston 1993, 1994).

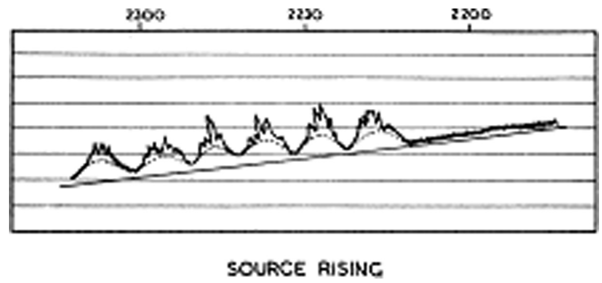

Figure 6 Sea interferometer fringes from Cygnus A, obtained at Dover Heights in 1947. The strong intensity variations visible near the fringe maxima were subsequently correlated with ionospheric scintillations (adapted from ATNF Historic Photographic Archive: 1166–12).

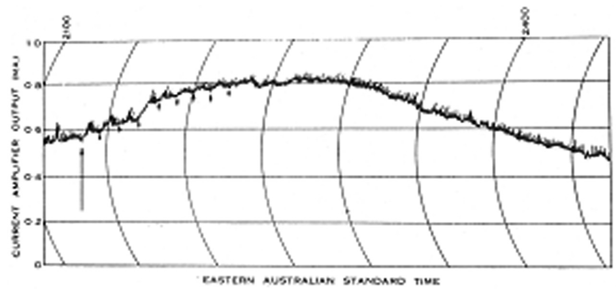

Figure 7 The detection chart record for Taurus A, obtained on 1947 November 6 (after Slee 1994).

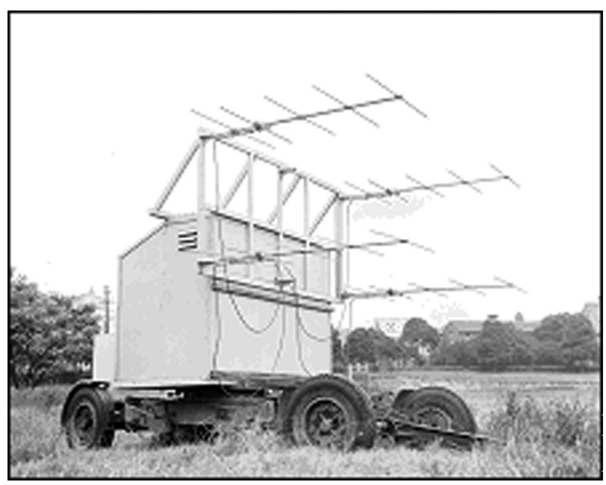

Figure 8 The mobile radio telescope and field laboratory used for the New Zealand observations of 1948 (ATNF Historic Photographic Archive: 1351–2).

Stanley was responsible for designing the mobile laboratory on which four 100-MHz Yagis were mounted in sea-interferometer mode (see Figure 8). Between early June and late September in 1948, Bolton and Stanley were at Leigh and then Piha, often under appalling weather conditions, but the observations and subsequent reductions (summarised by Slee 1994) resulted in positions for Cygnus A, Taurus A, Virgo A, and Centaurus A that were accurate to a few minutes of arc. This was precise enough to allow tentative optical identifications for the last three sources with bright optical objects (Bolton, Stanley, & Slee 1949). One of these (Taurus A) was the remarkable remnant of the supernova from 1054, known as the Crab Nebula. The last two sources, Virgo A and Centaurus A, appeared to be associated with M87 and NGC 5128, but because of the enormous radio luminosities involved Bolton, Stanley, and Slee were moved to speculate that these two nebulae might actually be peculiar galactic objects.

Frustratingly, there were no bright images within the error box of the strongest source, Cygnus A, and it took two further years of interferometer measurements before Graham Smith at Cambridge obtained a position that was accurate enough to identify the source with a faint elliptical galaxy whose radio luminosity was more than a thousand times that of M87 and NGC 5128. The realisation that there were such powerful sources of radio emission in the Universe attracted the attention of astronomers and physicists around the world, and brought radio astronomy to the forefront of astrophysical research.

Another important outcome of the New Zealand field trip was a partial resolution of the problem of the enigmatic intensity fluctuations, so conspicuous a feature in the Cygnus A fringes. Simultaneous observations of Cygnus A and the active Sun made by Slee at Dover Heights and by Bolton and Stanley in New Zealand showed conclusively that the Cygnus A variations were uncorrelated, while the solar bursts were in good agreement. Bolton, Slee, and Stanley were now certain that the Cygnus A fluctuations were not intrinsic to the source, but were probably scintillations caused by diffraction in the intervening medium, with the scale size of electron density turbulence less than 2000 km. Unfortunately, they did not publish this result until 1950 (Stanley & Slee 1950; cf. Bolton, Slee, & Stanley 1953), by which time groups at Cambridge and Jodrell Bank (following a private communication from the RP Group) had established an ionospheric origin, with scale sizes from 5 to 10 km.

During early 1949 an equatorially mounted 9-Yagi array was constructed by RP workshop staff and mounted on the blockhouse at Dover Heights. Interestingly, it was Stanley who suggested that a third axis be inserted between the polar and declination axes, which when rotated, converted the declination axis to an azimuth axis for sea interferometry (see Figure 9). After this antenna had been used by Bolton & Westfold (1950) for a complete sky survey at 100 MHz, Stanley and Slee used it in sea-interferometer mode to conduct a more sensitive source survey with the improved angular resolution of 17°. Some fourteen additional sources were discovered (Stanley & Slee 1950), including the now well known powerful radio galaxies Hydra A, Hercules A, Fornax A, and Pictor A. At the same time, Stanley and Slee also made more accurate measurements of the intensities of the four strongest sources with 2-Yagi antennas over the frequency range 40–160 MHz, publishing the first believable spectra, which strongly suggested that the radio emission was non-thermal (see figure 6 in Slee 1994).

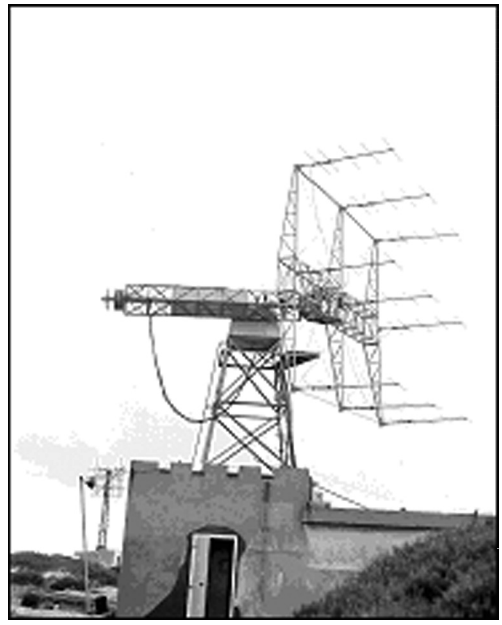

Figure 9 The 9-Yagi antenna set up in sea-interferometer mode in 1949 (ATNF Historic Photographic Archive: 1830–2).

Figure 10 Picturesque photograph of the 4.9-m dish on the roof of the blockhouse, complete with star trails (ATNF Historic Photographic Archive: 2810–1).

In 1950 Stanley was largely responsible for constructing a 4.9-m parabolic dish, which was eventually attached to the equatorial mounting on the blockhouse used formerly by the 9-Yagi antenna (Figure 10). This dish was intended as a test bed for low-noise receivers between 190

Figure 11 Gordon Stanley, in 1952 January, with the receivers that he developed for the 4.9-m dish and the short-lived 8-Yagi array (ATNF Historic Photographic Archive: 2650–1).

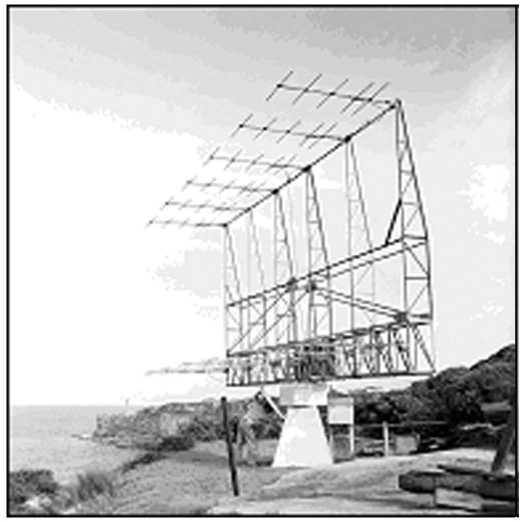

Figure 12 The 12-Yagi array, completed in early 1952, and used for the most comprehensive source survey carried out at Dover Heights (ATNF Historic Photographic Archive: 2763–5).

and 400 MHz, and was used in the sea interferometer mode on the stronger sources. At this stage Stanley was honing his skills in the design of low-noise crystal mixers and preamplifiers (Figure 11). A selection of sea interference patterns of Cygnus A over a decade of frequency can be seen in figure 3 of Bolton & Slee (1953), which shows dramatically how the ionospheric scintillations decrease rapidly at the highest frequencies.

In late 1951, Bolton, Stanley and Slee began constructing a new sea interferometer by mounting elements of the now-surplus 9-Yagi antenna on an azimuthal mounting located near the cliff edge a little to the south of the blockhouse. This was briefly an 8-Yagi array, but was soon converted to a 12-Yagi array, arranged in two wide-spaced banks of six Yagis. This antenna had a primary beam of only 12° in azimuth and $\sim$8° in elevation, and this improved resolution allowed them to measure declination by direction-finding to $\sim$1°, while the sudden rise time of the source could define the right ascension to $\sim$0.5°. This array can be seen in Figure 12. The operation of this final survey was made much easier by the use of a Miller integrator with a time constant of 30 min, which was used to suppress the large variation in Galactic background while allowing the comparatively short fringes through without suppression (see figure 9 in Slee 1994). This survey, published by Bolton, Stanley, and Slee in 1954, resulted in the detection of 122 sources with flux densities down to 40 Jy, and was the most comprehensive list of radio sources available at the time.

While the final sea interferometer survey was in progress, Bolton, Slee, and Stanley were able to start their final project — the construction of a large hole-in-the-sand parabola (see Orchiston & Slee 2002). They had realised the need to resolve the detail in the radio emission along the Galactic plane near the Galactic centre, while also having the ability to use a large telescope over a range

Figure 13 View of the prototype hole-in-the-ground antenna, looking towards the blockhouse (ATNF Historic Photographic Archive: 2763–2).

of frequencies in order to measure the radio spectra of the resolved sources. Funding from RP for a large steerable dish was not available, so the only feasible solution seemed to be a large transit parabola of long focal length. This could be used to survey a reasonably large area of sky by moving the focal point along the meridian plane, and allowing the Earth's rotation at each position to map a strip of the Galaxy. This was only possible from a site near Sydney's latitude, where the Galactic centre passes within 5° of the meridian. Bolton, Stanley, and Slee decided to first build a very cheap (indeed cost-free) 21.9-m prototype at 160 MHz, which, if successful, would allow them to apply for funds to upgrade and enlarge this in order to operate effectively at 400 MHz. The most practical way of creating this radio telescope was to dig the dish out of the deep sand on a fairly flat area some 150 m to the north of the blockhouse (Figure 13).

Bolton, Stanley, and Slee set to work during their lunch-breaks with a couple of wheelbarrows and shovels, and over a three month period shifted $\sim$1500 m^3 of sand, dumping the spoil around the rim of the depression to form a rough parabolic shape. While Stanley helped with this strenuous task, he was also designing the 160 MHz receiving equipment that would be used with the new dish. As the hole neared completion a rotating timber jig was built to achieve a usable parabolic shape. Stanley then took on the task of driving a truck to the Bunnerong Power Station to collect several loads of ash, which were worked into the sandy surface to help stabilise the shape. He finally collected many metres of steel strip from packing cases at the shipping terminal in Botany Bay, and these were laid in close parallel bands across the east–west dimension to form a reflecting surface. A guyed aluminium tube mounted on a rotatable east–west axis with a 160 MHz dipole at its top was erected at the vertex, and a low-noise 160 MHz preamplifier was installed in a shelter at the base of the mast. The signal was then fed to a mobile laboratory located just beyond the rim of the dish (to the extreme right in Figure 13), which contained the back end of the receiver and the chart recorder. The position of the beam in the meridian plane was set by measuring the elevation angle of the dipole with a theodolite, adjusting the nylon guy lengths until the required declination was achieved.

The brightness contours obtained were calibrated by using the measured flux density for Centaurus A, which lay within the surveyed region; the contours yielded believable values of brightness temperature but the angular resolution was still too low to reveal much structure in the 160 MHz Galactic brightness (see Bolton, Westfold, Stanley, & Slee 1954). Armed with these results, Bolton then released the fact that they had constructed a successful system, and Pawsey readily released the funds to upgrade the instrument to a 24.4-m hole-in-the-sand, which would operate with high efficiency at 400 MHz. This upgrade over the next three months involved building an accurately mounted template, laying a concrete surface in which a small-mesh chicken wire reflecting surface was imbedded, and cantilevering the antenna beyond the original rim by $\sim$2.5 m. A better quality aluminium focal mast with good-quality nylon guys was also installed. During this process, Stanley designed and tested a sensitive preamplifier and crystal mixer, which was preceded by an electronic Dicke switch. The completed 24.4-m antenna is shown in Figure 14.

By this time the team had been augmented by Dick McGee, who, with the assistance of Stanley and Slee, was responsible in early 1952 for conducting a survey of a 40° strip some 20° wide along the Galactic plane. The resulting brightness contours (McGee, Slee, & Stanley 1955) revealed several 400 MHz sources smaller than the 2° beam width. The strongest source was named Sagittarius A (Figure 15), and this was subsequently accepted by the International Astronomical Union as defining the centre of our Galaxy (see Goss & McGee 1996). Little could McGee, Slee, and Stanley have imagined that astronomers would later discover evidence of a black hole at the centre of our Galaxy.

Figure 14 The 24.4-m hole-in-the-ground antenna, with Gordon Stanley surveying the position of the aerial mast (ATNF Historic Photographic Archive: 3150–2).

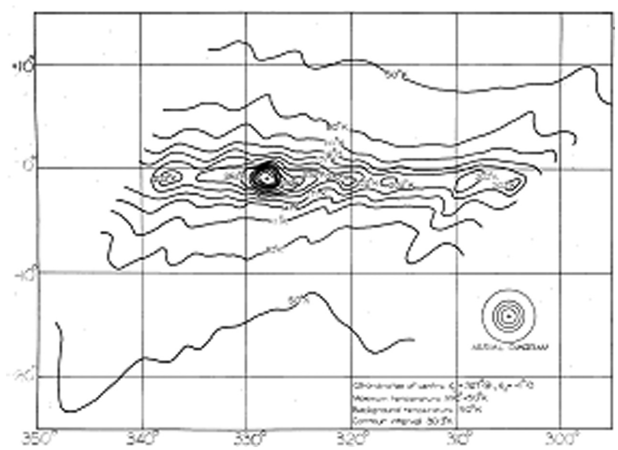

Figure 15 400 MHz contours obtained with the Mark II 'hole-in-the-ground' antenna, clearly showing the Galactic Centre source, Sgr-A, at $l = 328°$ and $b = -1.5°$ (ATNF Historic Photographic Archive: 3761–1).

After the completion of the 408 MHz survey, the 24.4-m dish was used at 327 MHz by Stanley & Price (1956) to search for the deuterium line as seen in absorption against the Sgr A and Cen A sources. However, no evidence of it was found, and even to this day the deuterium line has escaped detection.

The deuterium line search was the last radio astronomical project conducted at Dover Heights, and from 1954 the field station was used briefly by the cloud physics group within RP before being handed back to the Commonwealth Government. By this time, the Division's radio astronomical focus had shifted to the Potts Hill field station and a new field station at Fleurs.

During the seven years that Stanley spent at Dover Heights, the high-quality research carried out there led to astronomical discoveries that would change the course of astrophysical enquiry over the next generation. There is also little doubt that through this work his name quickly became known and respected in international astronomical circles. Yet throughout this period he retained his modest perspective and a quiet humorous outlook on his place in the overall scheme of things.

The Owens Valley Radio Observatory (OVRO)

Bolton and Stanley had a particularly close working relationship (Stanley 1974, 1986), and Stanley felt it keenly when Bolton transferred to cloud physics research at RP in 1953 (see Milne 1994) and then moved to Caltech in 1955 to start up a radio astronomy programme there. It surprised no-one, then, when Stanley left Australia in mid-1955 to join Bolton in California.

Although the first pioneering observations in radio astronomy had been made in the United States by Karl Jansky and Grote Reber in the 1930s, by the 1950s the United States had fallen far behind Australia and the UK in this rapidly developing field. With the support of the Chief of RP, Taffy Bowen, Bolton and Stanley went to Caltech to change the status quo and exploit the opportunity of complementing radio observations with those made with the large optical telescopes at the Mount Wilson and Palomar Observatories. Funding was readily acquired from the USA Office of Naval Research for the new radio observatory.

Stanley's first task was to build a 9.1-m parabolic antenna, and this was finished in 1956 and installed at Mount Palomar Observatory where it was used for H-line work. At about the same time, Bolton and Stanley began searching for a suitable site for Caltech's planned new radio observatory and, following what he later described as a 'frustrating search' throughout southern California for a site free of man-made radio interference, Stanley found the ideal location in the Owens Valley: 'Here stands the magnificent Sierra Nevada Mountains to the west with the Inyo Mountains to the east (about five miles apart) and continuing for about 100 miles, rising in parts to 14000 ft. There was no need to test, we had found the site!' (Stanley 1994). The first radio telescope on this site was a 25 MHz array of dipoles that was designed by Stanley (1974) specifically to investigate source scintillations, but it was only the forerunner to much more ambitious plans that Bolton and Stanley had for the Owens Valley Radio Observatory.

At this time, radio telescopes fell into two main categories: those operating at metre wavelengths which used wire arrays, often in the form of interferometers, and those working at the shorter decimetre and centimetre wavelengths which used single parabolic dishes. Stanley, Bolton, and Bruce Rule, Caltech's Chief Engineer, designed the first radio interferometer operating above a few hundred megahertz by using a pair of large 27.4-m parabolic dishes mounted on wheels and capable of being positioned at stations along a 487.7-m railway track (see the two left-hand antennas in Figure 16). This novel interferometer became fully operational in 1960, but soon after this Bolton returned to Australia to take up the inaugural Directorship of the Parkes Radio Telescope (see Goddard & Milne 1994). Stanley was subsequently appointed Director of the OVRO, a post he viewed with some ambivalence given that he regarded himself as a radio engineer rather than an astronomer, and that he 'preferred to remain in the background' (Stanley 1984).

Figure 16 Gordon Stanley at the Owens Valley Radio Observatory (courtesy: Robert Cowan).

Nevertheless, the Owens Valley interferometer quickly became one of the premier radio telescopes in the world, based largely on the instrumentation developed by Stanley and Caltech graduate students Bob Wilson, Alan Moffett, and Dick Read, and radio source coordinates were determined with unprecedented accuracy. In collaboration with astronomers from Caltech and the Mount Wilson and Palomar Observatories, the programme of the OVRO led to the identification of radio galaxies at ever-increasing redshifts (e.g. Minkowski 1960). Other programmes were aimed at determining the two-dimensional brightness distribution of radio galaxies (Maltby & Moffet 1962), radio source spectra (Kellermann 1964) and polarisation (e.g. Berge & Seielstad 1967), the study of planetary atmospheres and surfaces (e.g. Berge 1968) including Jupiter's unique radiation belts (Radhakrishnan & Roberts 1960), interstellar hydrogen clouds (Clark 1965), and the first high-frequency Galactic plane survey (Wilson & Bolton 1960). Most of the work was done by students and postdoctoral fellows, but they all depended on the series of low-noise radiometers which Stanley built for ever-shorter wavelengths. As he had previously done at RP, Stanley recognised the need to observe at shorter and shorter wavelengths, for improved resolution (to minimise the effects of confusion and to obtain increased positional accuracy) and in order to obtain spectral information about radio sources. Initially Stanley planned to operate the OVRO interferometer at 400 MHz, but this was soon changed to 750 MHz, and by the time the interferometer went into operation the observing frequency was 960 MHz. Soon after, 1420 MHz became a standard operating wavelength, both for continuum and HI spectral line studies.

Figure 17 Gordon Stanley, the supreme designer, builder, and fixer of anything electronic (courtesy: Dan Harris).

Stanley's receivers used 1N21 diode mixers followed by low-noise triode amplifiers obtained from Bell Laboratories to produce the most sensitive radiometers then in use for radio astronomy, and which were affectionately known as 'Stanley Steamers'. He took particular pride in comparing his receivers with those at NRAO, which used expensive parametric amplifiers but which had several times poorer sensitivity. He taught one of us (K.I.K.) how to repair a noisy receiver by tapping the diode mixer with a hammer or, if no hammer was available, by dropping it on the floor. Most of the time, this ended up with the receiver not working at all, but in a few cases, the original very low noise performance was miraculously restored! At this time, Stanley (Figure 17) was known to his students as someone who could design, build, and fix just about anything that involved electronics.

While at Caltech, Stanley much preferred to design and construct instrumentation rather than use it for research, and consequently his published research output was modest. His earliest research project involved an H-line study using the Palomar antenna (Bolton, Stanley, & Harris 1958), and this was followed by the observation of an occultation of Taurus A by the solar corona with the Owens Valley 25-MHz array (Bolton, Stanley, & Clark 1958). In this study, they were able to establish the existence of scattering by the solar corona out to much greater distances than had hitherto been determined by other workers operating at higher frequencies.

Although the only serious research programme Stanley carried out with the OVRO interferometer was a study of Jupiter's radiation belts (Roberts & Stanley 1959) in which he collaborated with Jim Roberts (a visitor from RP), he played a pivotal role in all of the research conducted by the Department's graduate students and post-doctoral fellows.

The 1960s were the golden years of radio astronomy, and Caltech was in the middle of the radio astronomy world and pre-eminent in the United States. Many of the students and post-doctoral fellows went on to productive careers in radio astronomy. Bob Wilson, together with Arno Penzias, discovered the cosmic microwave background at Bell Laboratories; Barry Clark played a major role in the design and construction of the Very Large Array and the Very Long Baseline Arrays at the National Radio Astronomy Observatory; Venkataraman Radhakrishnan later returned to India to become Director of the Raman Research Institute; and Alan Moffet, who had used the Owens Valley interferometer to investigate the complex nature of radio galaxies as a graduate student, later succeeded Stanley as Director of the OVRO. Meanwhile, one of the authors (K.I.K.) has been at NRAO for many years, was briefly at the MPIfR in Bonn and, like Radhakrishnan, spent several years at RP doing radio astronomy.

In later years, Stanley (1994) recalled with warmth the staff and students at the OVRO, particularly Al Munger, the site superintendent, and Rachel Gates, the housekeeper and cook, whom he described as a living legend at the Observatory. Gates, who was part Texan and part Cherokee, ran the OVRO living quarters with an iron hand and acted as a substitute parent for the radio astronomy graduate students who spent long periods in residence at the Observatory. Al Munger, who did everything from operating tractors, bulldozers, and cranes to supervising the other staff, was known as 'Big Al' to distinguish him from 'Little Al' Moffet (who was then a graduate student).

Stanley never enjoyed the administrative responsibilities associated with being the Director of a major government-funded university research facility and the ever-increasing levels of bureaucracy from Caltech and the NSF. But he rose to the task and managed to obtain the funds needed to keep the Observatory operating and, indeed, expanding into new areas. However, his ambitious plan to build a large array to replace the OVRO interferometer was never funded. By the early 1960s the success of the OVRO interferometer and the Cambridge synthesis radio telescopes had demonstrated the power of synthesis arrays, and a National Academy of Sciences study recommended the construction in the United States of a large array with a resolution of a few arcseconds (Whitford 1964). Fierce competition developed between Caltech's plan to construct eight movable antennas, each 39.6-m in diameter, and a more elaborate (and more expensive) proposal from the NRAO to build the 27-element VLA. Repeated reviews by the NSF encouraged the further development of the Owens Valley Array (see Kellermann & Moran 1999), but only one of the 39.6-m dishes was ever built (see Figure 16). Instead, the NSF funded the construction of the NRAO VLA. Meanwhile, the OVRO 39.6-m antenna had a long and honorable life as a key part of the USA VLBI Network, and it was also used with the existing pair of 27.4-m antennas as a connected three-element interferometer.

Figure 18 A hale and hearty Gordon Stanley in 2000 (courtesy: Joyce Hales).

The Post-Caltech Years

Gordon Stanley retired from Caltech in 1975 to return to his true love — radio engineering. He accepted a position near his new home in Santa Barbara, California, with Kilovac, which manufactured high voltage solid state switches, radio-frequency relay switches, and heart defibrillators. During his short two-year stay at Kilovac, Stanley was influential in re-organising their shop, in establishing a high level of quality assurance, doubling the production rate (to the delight of the President) and, reflecting on his early Radiophysics experiences, obtaining better benefits for women workers in the company.

He then went to work for a small technical company, Spacek, but shortly after he joined the company, the owner, George Spacek, sold out to Honeywell. Little is known about his activities during this period other than that he worked on classified microwave devices. However, he did become familiar with running a small business, and he left Honeywell to start his own company. Stanley Microwave Systems (SMS) developed equipment for the US Navy, instrumentation to measure the temperature of sea ice for the University of Washington Oceanographic Institute, and, at the request of the Japanese government, a device to measure the temperature of the upper atmosphere. Following the push to shorter wavelengths begun at RP and continued at Caltech, SMS developed equipment working up to 100 GHz.

From the time Stanley moved to the United States in 1955, he continued to enjoy literature, poetry, art, and politics, as well as science and electronics. He loved music, could quote at length from Shakespeare, and balanced these interests with a lifelong love of sports. Throughout his life he impressed on his colleagues, his students, and his children the need to be self sufficient and to be able to fix anything, whether in the laboratory or at home.

In 1982, Gordon and Helen moved to the pleasant Carmel Valley area in California where they continued to enjoy life (Figure 18) and their growing family of grandchildren until he died from complications of progressive supranuclear palsy on 2001 December 17.

Concluding Remarks

Gordon Stanley's productive years at the CSIRO's Division of Radiophysics brought him to the attention of the international astronomical community at a very young age. The work at Dover heights, in which he played a major role, was responsible for a seminal leap in our understanding of the high-energy physics of the Universe, and influenced the course of astronomy and astrophysics over ensuing generations.

In contrast, his work at Caltech from 1955 to 1975 was primarily restricted to the engineering challenges associated with the construction of a large, modern radio astronomy facility in the Owens Valley, which went on to exploit the discoveries made during his Dover Heights years. Despite these very real achievements at Owens Valley, Stanley (1986) missed the exhilaration of those pioneering Dover Heights days, and he lamented the fact that '. . . never once have I recaptured anything like the excitement of those first few [years]' (Stanley 1974).

Throughout his long and varied career, Gordon Stanley had a very strong work ethic, while remaining modest about his own achievements. He was proud of the accomplishments of the OVRO, but throughout his tenure as Director, he never put his name on any publication by students or staff of the Observatory. He had great respect for the contributions of his students, if not their sometimes difficult personalities.

Accessory Materials

Figure A1 shows the major radio astronomy field stations in and near Sydney, 1945–1960 (1 Badgery's Creek, 2 Dover Heights, 3 Fleurs, 4 Georges Heights, 5 Hornsby Valley, 6 Murraybank, 7 Penrith, 8 Potts Hill, 9 Dapto; the dotted boundaries indicate the present-day Greater Sydney and Wollongong regions); Figure A2 shows Bruce Slee, the third member of the 'radio stars' team, photographed beside a Dover Heights commemorative plaque in 1989 (adapted from ATNF Historic Photographic Archive: 15506–6). These are available from the authors or, until January 2010, from *Publications of the Astronomical Society of Australia*.

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